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Evaluation of RF Anechoic Chamber Fire Protection Systems

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by

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FOREWORD

This special study was carried out by and this report was prepared by the DOD Guidance and Control Information Analysis Center (GACIAC). It was jointly funded by the Naval Air Systems Command (Harpoon Program) under AirTask A5422041/0086/0000/000001 Work Unit E2041G-A/RGM 84-1 and Naval Weapons Center (NWC) overhead. The study was conducted for NWC as a special GACIAC task under Contract No. DSA900-77-C-3840 Line Item 0001AJ. NWC is planning to construct a number of microwave anechoic chambers over the next few years and is concerned about the fire protection aspects of these facilities.

IIT Research Institute (IITRI) has been involved in the operation and maintenance of a large chamber at Wright-Patterson Air Force Base and provided information and analysis of the fire protection system installed in that facility. IITRI also has an active Fire Protection Engineering group, having considerable background in this general area, that participated in this study. In this effort, IITRI was assisted by Gage Babcock and Associates (J. A. Campbell), a nationally recognized fire protection consulting firm.

It is hoped that the findings and recommendations presented in this report will be of value to those involved in the planning of future chambers and that the end result will be a heightened awareness of the methods for improving the fire protection systems and for reducing the susceptibility to fires.

This report is for information only. It does not represent the official views of the Center nor have the contents been independently verified by NWC personnel.

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(U) The increasing use of microwave anechoic chambers plus several recent chamber fires was the impetus for this special study. The report identifies and collects in one document the various issues and problems associated with the fire protection of anechoic chambers. It also addresses the interfaces between personnel groups including the chamber designers, operators, maintenance and the fire department. It is not a design report; i.e., it does not contain enough detail to design either a chamber or the fire protection system. Instead, it presents the pros and cons of the various fire protection options available to the designers (smoke and heat detectors, alarm systems, sprinkler heads, preferred physical locations, fire suppressant agents, etc.) and relates these to chamber operation. The report also identifies several areas where additional investigation is required such as detection of deep-seated combustion, testing of new more fire-resistant absorber materials, and analysis of the combustion products of halogen-type suppressants. An extensive list of references is included.

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EVALUATION OF RF ANECHOIC CHAMBER FIRE PROTECTION SYSTEMS

1. INTRODUCTION

This special GACIAC task to review and evaluate fire protection systems for microwave anechoic chambers was undertaken in response to a request from Mr. E. F. Diede, Code 36303, Naval Weapons Center, China Lake, California. NWC is planning to construct a number of anechoic chambers over the next few years and needed an independent review of the current status and future trends in fire protection systems and fire resistant microwave absorber materials. Because of the unique characteristics required of a microwave anechoic chamber, the interior surfaces are lined with carbon impregnated foam to suppress electromagnetic reflections. This material can support combustion and as a result a number of fires have occurred inside such chambers. These fires have stemmed from a number of causes, i.e., electrical shorts, open flame, and overheating caused by soldering. Because of these fires, manufacturers have developed new fire resistant materials which show promise for reducing the susceptibility to fires in future chambers. However, this material must be specified in the construction contract because it is more costly than the untreated materials which are still available.

These, as well as other aspects of fire protection systems, are discussed in the following sections. They are intended to present a summary of the findings of this study and to provide general recommendations regarding the selection and installation of fire protection systems for microwave anechoic chambers.

2. ELECTRICAL ENGINEERING CONSIDERATIONS

An RF anechoic chamber is especially designed and constructed to be electrically "quiet," i.e., to simulate free space, by suppressing the reflection of electromagnetic waves from the interior surfaces of the chamber. In many cases, shielding is also employed to keep external radiation from entering the chamber or internal radiation from escaping. The absorbent material's susceptibility to fire and the effects of fire protection equipment on both the quietness and shielding effectiveness are important considerations addressed in the following paragraphs.

2.1 Characteristics of Microwave Absorbent Materials

Although it appears that the electrical characteristics of microwave absorbent materials have not improved much in recent years, their fire retardancy characteristics have greatly improved. Several years ago it became apparent that anechoic chambers were quite vulnerable to fire, largely because of the flammability of the absorber materials.

Since these materials derive microwave absorbing properties from loading through carbon impregnation, they are conductors of electricity and could be ignited by electric currents. This was believed to be the cause of the 1973 fire that occurred in a Northwestern University chamber (Ref. 1).

Since high-quality absorber materials are made of a base material that is typically urethane foam, another source of possible ignition is exposure to an open flame or intense heat. Untreated urethane foam can be readily ignited when exposed to no more than a lighted match. Absorber foams of the "self-extinguishing" type would not burn as readily as untreated foam but could still contribute significantly to the severity of a chamber fire. This type of ignition, aided by the fact that flammable glue had been used to adhere the absorber materials to the chamber walls, was believed to be the cause of the 1979

fire that occurred in a Hughes Aircraft Company chamber. This type of ignition was also the cause of the 1974 fire that occurred in a Naval Air Rework Facility chamber (Ref. 2).

Urethane foam materials can continue to smolder after the source of ignition has been removed and the fire appears to be out, which is an additional problem that has been addressed in recent years. Also, large amounts of toxic gases can be produced by the burning foam, which was a problem particularly noted in the 1973 fire that occurred in a Naval Research Laboratory chamber (Ref. 3). Toxic gases produced by burning foam in one part of a chamber can be absorbed by foam unaffected directly by the fire in other parts of the chamber. Therefore, outgassing of toxic fumes from the foam that appears to be in good condition can result in the chamber having a hazardous environment long after (weeks, perhaps months) the fire has occurred. The result is that even foam that appears to be in good condition may have to be replaced after a fire has occurred unless the foam that burned meets low toxicity standards.

The above problems associated with urethane foams (ignition by electric currents, ignition by exposure to an open flame or intense heat, smoldering, and generation of toxic gases) have resulted in investigations by the Naval Research Laboratory which have led to the development of standards for the absorber products industry (Ref. 4). Additional research at NRL resulted in up-dated standards (Ref. 5), which apparently have not been adopted, or cannot be met, by the industry. In fact, only Emerson & Cumming makes reference to the earlier standards and no one in the industry refers to the updated standards as yet. The performance standards from the above two references are provided in Appendices A and B of this report.

A review of advertising and manufacturer directories indicates that there are only three significant sources of microwave

anechoic chamber absorption materials in the United States: Emerson & Cumming, Advanced Absorber Products, and Rantec. Although, perhaps, Plessey materials may still be available from European sources, orders for the U.S. manufacturing plant were curtailed in late 1979. Therefore, the remainder of this report will only make reference to the three principle sources listed above.

2.1.1 Mechanical Characteristics

Broadband microwave absorbers useful in anechoic chambers are made from a variety of base materials: urethane foam, rubberized fibers, polystyrene foam, silicone rubber foam, ceramic foam, fiberglass, and ferrite tile.

A reflectivity of -50 dB or better at normal incidence is common using pyramid-shaped, carbon-impregnated urethane foam. Apparently, no other material in common use is capable of such a low level of reflectivity. Therefore, in anechoic chambers where the best performance is desired (i.e., minimum reflections), carbon impregnated urethane foams are used. Other base materials are selected when other factors take priority over minimum reflections, i.e., cost, material rigidity, service temperature, power handling capability, fire retardancy, fuel oil resistance, etc. In this report, because it is assumed that optimum reflectivity performance is desired, carbon-impregnated urethane foam is of greatest interest.

Carbon-impregnated urethane foam is usually supplied in 24" by 24" blocks of pyramidal-textured material. Greater pyramid length (depth) is associated with better low-frequency reflectivity characteristics.

2.1.2 Electrical Characteristics

Electrical characteristics of absorber material include: reflectivity for normal incidence and other angles of incidence at specified frequencies, range of frequencies where the reflectivity is better than some specified value, maximum service

temperature, and power handling capability. For comparison purposes, two sizes, 8" and 18", of highest-quality carbon-impregnated foam were selected from the data sheets of the three principal sources. The electrical characteristics, as well as mechanical characteristics, fire retardancy, and cost are presented in Tables 1 and 2.

2.1.3 Fire Retardancy

Certain microwave absorber materials are considered non-burning. For example, Emerson & Cumming says: "ECCOSORB HT will not burn" (Ref. 6). However, ECCOSORB HT has a basic composition of ceramic foam and the best reflectivity rating is -17 dB which, of course, does not compare faborably to the -50 dB or better available from carbon-impregnated urethane foam. Other microwave absorber materials are also considered non-burning; however, as stated above, in anechoic chambers where minimum reflections are desired, carbon-impregnated urethane foams are normally used.

Unfortunately, untreated carbon-impregnated urethane foam burns. As mentioned above, ignition by electric currents, ignition by exposure to an open flame or intense heat, smoldering, and generation of toxic gases are all problems associated with the use of carbon-impregnated urethane foams. The problem can be partially overcome, but not eliminated, by treatment with chemical fire retardants (Refs. 7-12). These references, as well as Ref. 4 and Ref. 5, are primarily concerned with the problems of ignition, smoldering, tests that can be performed to determine the hazards of such materials, and the toxic gases produced by a fire environment and either aggravated by and/or transported by fire-fighting techniques.

Considerable progress has been made in recent years in improving the fire retardancy of carbon-impregnated urethane foam; however, additional research is needed in this area and the results of current testing programs have not yet been

TABLE 1. A Comparison Of Absorber Products, 18-Inch.[1]

	E&C VHP-18	AAP-18	Rantec EHP-18
Composition	urethane foam	foam	urethane foam
Geometry	pyramidal	pyramidal	pyramidal
Color	light blue standard, other pastel colors, white, and black available	light blue standard, black and other colors available	---
Height or Thickness	18"	18"	18"
Base dimension of each block	24" by 24"	24" by 24"	24" by 24"
Weight of each block	6 lbs.	---	---
Peaks per block	---	16	16
Corner blocks available	yes	---	yes
Service temp.	to 250°F	---	---

TABLE I. (Cont.)

	E&C VHP-18	AAP-18	Rantec EHP-18
Power handling	2.0 watts/sq.in.	---	---
Fuel oil resistance	special treatment	---	---
Fire retardancy	conforms to nonflammability requirements of ASTM D-1692-74, NRL fire retardant grade available and meets requirements of tests 1, 2, and 3 of NRL Report 7793[2] see E&C Tech. Bul. 8-2-3	self-extinguishing per ASTM-1692, FR fire retardant grade available: see AAP Test Report TR-100[3]	-, CL fire retardant grade available: see Rantec Tech. Bul. F-2[4], tests are similar to tests 1, 2, and 3 of NRL Report 7793
Lowest frequency for -30dB reflectivity[5]	500MHz	500MHz	500MHz
Lowest frequency for -40dB reflectivity[5]	1GHz	1GHz	1GHz[6]

TABLE 1. (Cont.)

	E&C VHP-18	AAP-18	Rantec EHP-18
Lowest frequency for -50dB reflectivity(5)	5GHz	4GHz(7)	4GHz(7)
Small quantity cost per block(8)	∿ $65 for NRL grade	∿ $47 for standard ∿ $54 for FR grade	∿ $40 for standard ∿ $48 for CL grade

(1) Information obtained from manufacturer's data sheets received in December 1979 and January 1980.

(2) "Performance Specifications for Anechoic-Chamber Materials", taken from NRL Report 7793, is Appendix A of this report.

(3) AAP Test Report TR-100 is Appendix C of this report.

(4) Rantec Technical Bulletin F-2 is Appendix D of this report.

(5) For angles near normal.

(6) Designated as L Band by manufacturer.

(7) Designated as C Band by manufacturer.

(8) Prices obtained by phone on January 8, 1980.

TABLE 2. A Comparison Of Absorber Products, 8-Inch.[1]

	E&C VHP-8	AAP-8	Rantec EHP-8
Height or thickness	8"	8"	8½"
Base dimension of each block	24" by 24"	24" by 24"	24" by 24"
Weight of each block	4 lbs.	---	---
Peaks per block	---	81	64
Lowest frequency for -30dB reflectivity[2]	1GHz	1GHz	1GHz[3]
Lowest frequency for -40dB reflectivity[2]	3GHz	2GHz[4]	2GHz[4]
Lowest frequency for -50dB reflectivity[2]	10GHz	8GHz[5]	8GHz[5]
Small quantity cost per block[6]	∿ $50 for NRL grade	∿ $29 for standard ∿ $34 for FR grade	∿ $23 for standard ∿ $30 for CL grade

(1) Information obtained from manufacturer's data sheets received in December 1979 and January 1980. Composition, geometry, color, corner blocks available, service temperature, power handling, fuel oil resistance, and fire retardancy the same as in Table 1.
(2) For angles near normal.
(3) Designated as L Band by manufacturer.
(4) Designated as S Band by manufacturer.
(5) Designated as X Band by manufacturer.
(6) Prices obtained by phone on January 8,1980.

evaluated. Just how effective current fire retardant techniques are in the event of a full-scale chamber fire are not known. The best method of putting out, or at least suppressing, such a fire is controversial and depends upon such factors as the size of the fire, the ability to detect and respond quickly to the fire, and the basic question of what it is that most needs to be protected (e.g., the chamber, the equipment in the chamber, or the parent building).

A limited full-scale chamber fire testing program is presently underway at Factory Mutual Research Corporation (Norwood, Massachusetts). At the time of this writing two full-scale chamber fire tests have been conducted containing Rantec or Emerson and Cummings absorber materials, and a Fenwal fire protection system with Halon 1301 gas. A full-scale burn with Advanced Absorber Products will also be conducted. It will be several months before the test data are reduced and made public. This expensive testing program should reveal useful data; however, many unanswered questions will still remain. For example, monitoring toxic gas levels generated by the burning foam and determining how much the Halon 1301 gas contributes to the toxic gas levels is apparently not part of the current testing program at Factory Mutual.

Therefore, at the present time it is not possible to state which of the available carbon-impregnated foams is superior in terms of fire retardancy. It is, however, worth noting that Emerson & Cumming apparently has the most active program of research and testing of the three manufacturers considered here.

The fire retardancy characteristics of the three manufacturers highest-quality carbon-impregnated foam absorbers are briefly stated in Table 1.

2.1.4 Recommendations

The use of carbon-impregnated urethane foam in anechoic chambers poses a unique fire hazard, and therefore only materials that represent the state-of-the-art in fire retardancy should be used. Not only should the materials have excellent fire retardancy characteristics (difficult to ignite and be highly self-extinguishing), but they should have very low toxic gas emissions. It is known that burning or smoldering carbon-impregnated urethane foam gives off HCN, HCl, and CO, all of which can be carried from the fire scene and can cause respiratory problems for fire fighters and others, and can cause death even when only mild respiratory discomfort is initially experienced. HCN has the additional property that it can enter the blood stream by absorption through the skin as well as through inhalation (Refs. 4, 5, 8-10, 12).

Since the three manufacturers do not refer to the same standards of fire retardancy (two have devised their own testing procedures), and very little data is supplied by them about the fire retardancy of their products, it is impossible to compare them on this basis. Therefore, it is recommended that the Naval Weapons Center, China Lake, or its designate, conduct tests on the three considered materials following the testing procedure outlined in NRL Report 8093 (Ref. 5). See Appendix B.

The tests should be conducted not simply on a pass-fail basis, but rather the data should be carefully compared as the one that performs the best in these tests is likely to be the one that would perform the best in a fire environment.

Of course, the results of the full-scale burn tests presently being conducted by Factory Mutual could also be of great help in the evaluation. They should be contacted to obtain information on this series of tests by anyone comtemplating the construction of an anechoic chamber.

In lieu of any testing program by the Naval Weapons Center, and in the absence of any data from the Factory Mutual tests, it is recommended that the anechoic absorber materials selected for future chamber construction be specially treated and/or formulated for fire retardancy and that their specifications address the NRL standards that have been prepared.

2.2 Considerations of Electrical and Mechanical Penetrations of a Shielded Anechoic Chamber

There are two basic considerations with regard to maintaining the shielding effectiveness of an enclosure; these considerations relate to the purpose of the shielded enclosure. In most cases the principal purpose of the shield is to eliminate or minimize internal voltage fluctuations due to external sources (i.e., EM fields and/or injected currents). In other cases, covert testing in an RF anechoic chamber is of interest, and it is necessary to prevent internal EM fields or conducted currents from emanating from the enclosure.

In either case the shielding effectiveness must be considered. At lower frequencies (i.e., below approximately 100 KHz) it is the shield materials which are the primary controlling factors for isolating EM fields. At higher frequencies, on the other hand, the penetrations of the shield and the apertures associated with the penetrations are the dominant factors affecting the EM fields. Uncontrolled penetrations of the shielding can result in induced currents on conductors at all frequencies and degrade the shielding effectiveness of the entire chamber. Control of these necessary penetrations is the subject of this discussion. References 13-18 address the concepts discussed here in greater detail.

2.2.1 General Concepts

There are three (3) basic methods of limiting the energy which penetrates a shielded facility. These are: (1) diversion, where the energy is shunted from the facility by means of the

grounding system; (2) reflection, where the energy is reflected back onto the penetrating conductor due to an impedance mismatch; and (3) absorption, where the undesired energy is absorbed in a lossy medium at the entry point into the facility. These are depicted in simplified form in Figure 1. As depicted in Figure 1, these concepts are to keep undesired energy present on the penetrant (wires, pipes or ducts) from entering the protected (shielded) space. These concepts could also be applied to limit emanations from the protected space.

Often the devices or techniques for implementing these concepts require two or more of these mechanisms to be applied simultaneously. These concepts can be applied to control the penetrating energy present on both mechanical (i.e., pipes, conduits, etc.) and electrical (i.e., control and signal wires, power lines, etc.) penetrants. These concepts are presented in more detail in the following subsections.

2.2.1.1 Current Diversion Techniques

The basic mechanism in the case of current diversion is to shunt the undesired current to the shield or ground by means of a low impedance path. This technique is often used to shunt the energy induced on conducting mechanical penetrants, cable shields and electrical conduits. Typical examples employing this concept are depicted in Figure 2.

Figure 2a depicts control by the current diversion mechanism for the exterior conductor of a penetrant. This approach is applicable for shunting the current from electrical conduits, water/fuel/etc. pipes, waveguides, and control or signal cable shields. The undesired energy is shunted onto the facility shield or to ground since these current paths, if the penetrant is properly terminated on the facility shield, are the lowest impedance path.

Proper termination requires a very low impedance bond to the facility wall at the exterior/interior surface (depending

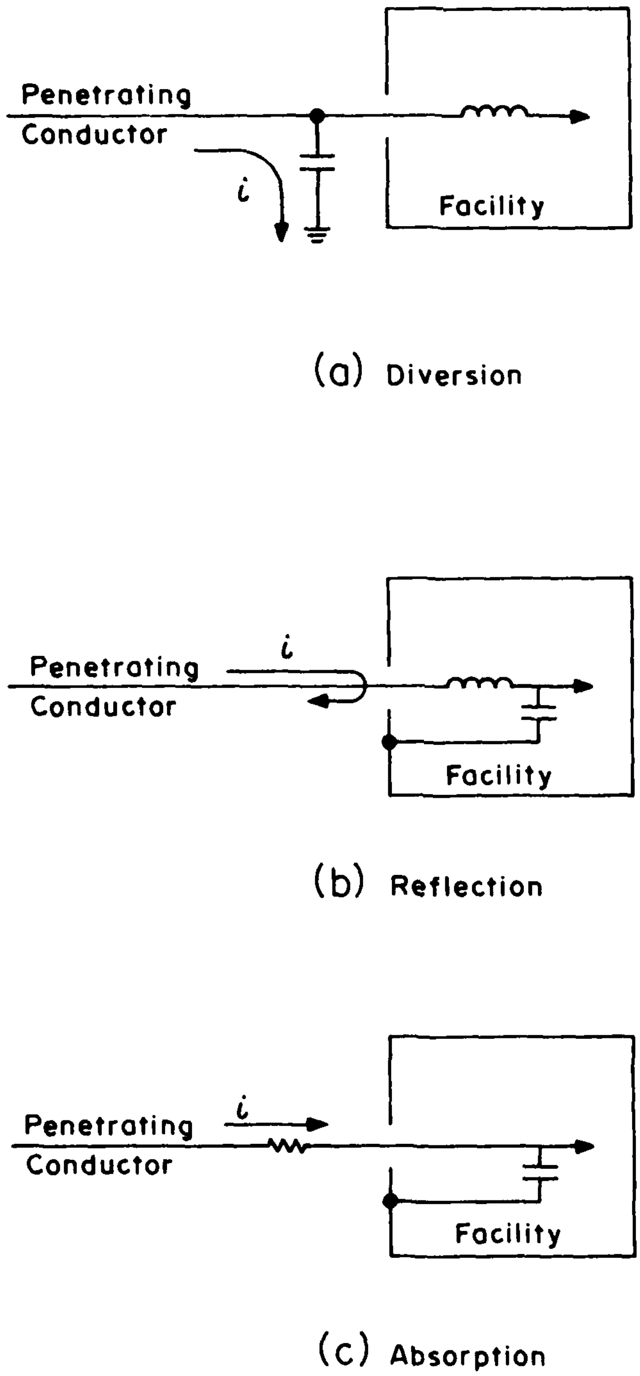

FIGURE 1. Conceptual Methods of Limiting Energy Penetrating a Facility.

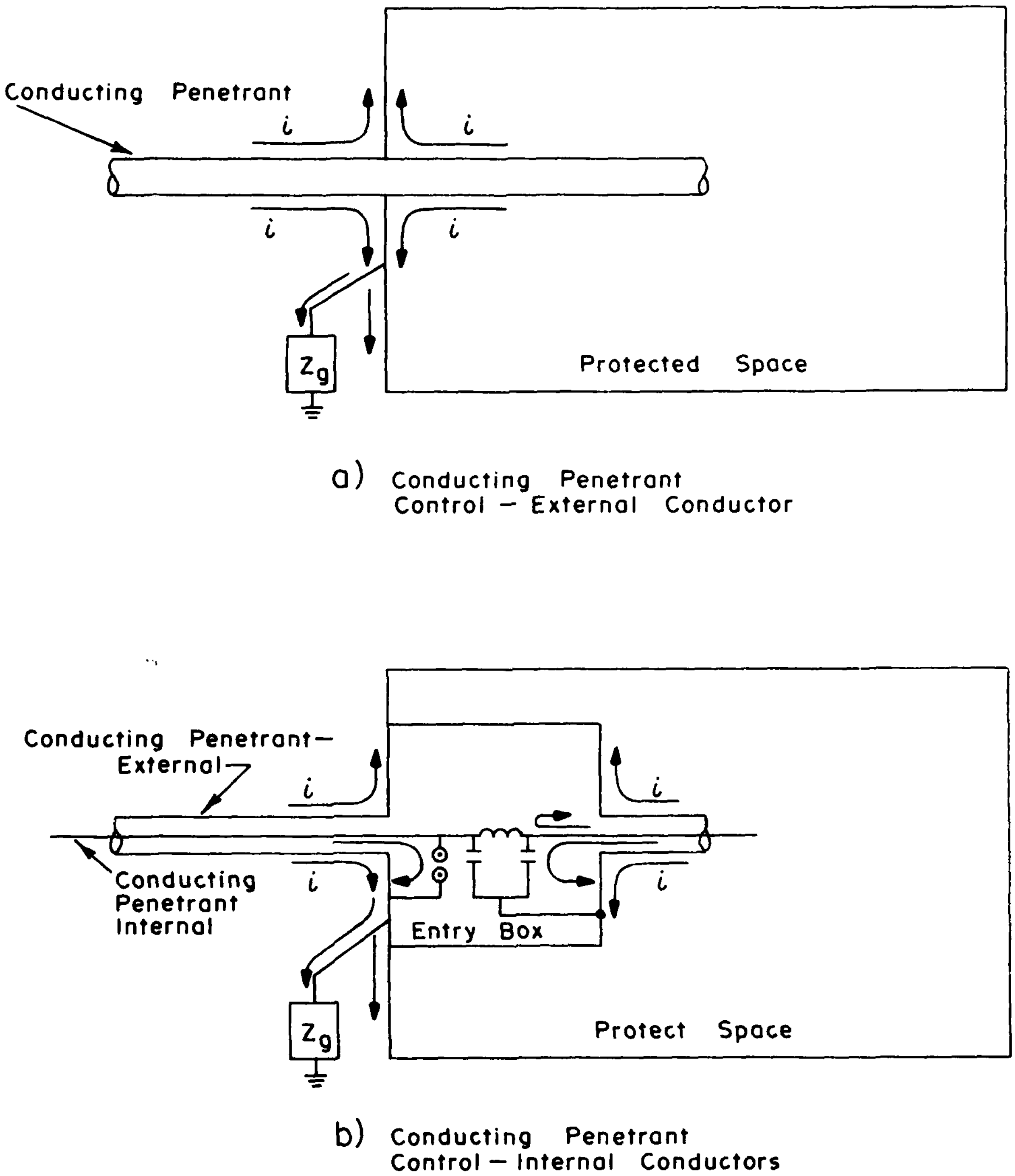

FIGURE 2. Current Diversion Techniques.

on whether exterior/interior currents are being considered) at the highest frequency of interest with regard to the undesired energy to be controlled. In the case of exterior currents/energy entering the protected space, the currents are shunted to the exterior surface of the facility shield. Interior currents are shunted to the interior surface of the shield. To achieve the required low impedance bond between the facility shield and electrical conduits and/or mechanical penetrations (pipes), welding or soldering may be employed to provide a good electrical connection of the penetrant to the facility shield at the point of entry. An alternate technique would be the use of a threaded connector with the bulkhead feedthrough welded to the wall. The threaded connector technique is also applicable for terminating the RF shields on control or signal wires. To obtain the required low impedance, a full 360° contact termination is required.

It is desirable, in order to minimize diffusion of the undesired currents through the facility shield, to shunt the currents to "ground" (earth or building ground). This requires a low impedance bond to the earth electrode system and a low impedance from the earth electrode system to earth. This is often very difficult to achieve at high frequencies (100 MHz and higher).

The same technique is depicted in Figure 2b for the exterior conductors, but also illustrates control of the interior conductors. The undesired currents on interior conductors may also be shunted to the shield surfaces (interior or exterior depending on the current source). This requires that proper isolation between the internal conductor and the shield be provided so that the desired signal is not degraded. This isolation may be provided by amplitude limiters (e.g., surge arresters, zener or switching diodes) or spectral limiters (bandpass, highpass or lowpass filters or bypass capacitors). It should be noted that limiting the energy on internal conductors requires

the use of a shielded entry box at the point of entry into the protected space.

2.2.1.2 Current Reflection Techniques

If a large discontinuity in the characteristic impedance of the penetrating conductor is introduced near the facility wall, the undesired energy propagating toward the discontinuity will be reflected back to the source. Since either a short circuit or an open circuit will produce such a reflection, the impedance required may be either very small or very large compared to the characteristic impedance of the penetrating member.

One such approach was shown in Figure 2b, utilizing an amplitude or spectral limiter or both, and will not be repeated here.

Other techniques for reflecting the penetration current are depicted in Figure 3. Figures 3a, 3b, 3c are techniques for data transmission through the facility shield wall. Figure 3d shows the use of a non-conducting section of pipe used to reflect the current. If high energy levels are encountered, care must be taken in this type of application since a high voltage may exist between conducting sections. Also, depending on the size (cross-sectional area) of the penetrant, significant leakage into/out of the facility can be experienced since the aperture would represent a propagating structure at higher frequencies.

2.2.1.3 Energy Absorption Techniques

This category is a special case of the concepts discussed above. The objective is to absorb the undesired energy rather than reflect it or shunt it onto the facility shield. It implies shunting the currents to earth (a lossy medium) utilizing lossy filters (e.g., containing ferrites or resistive elements), or the use of ferrite beads, etc.

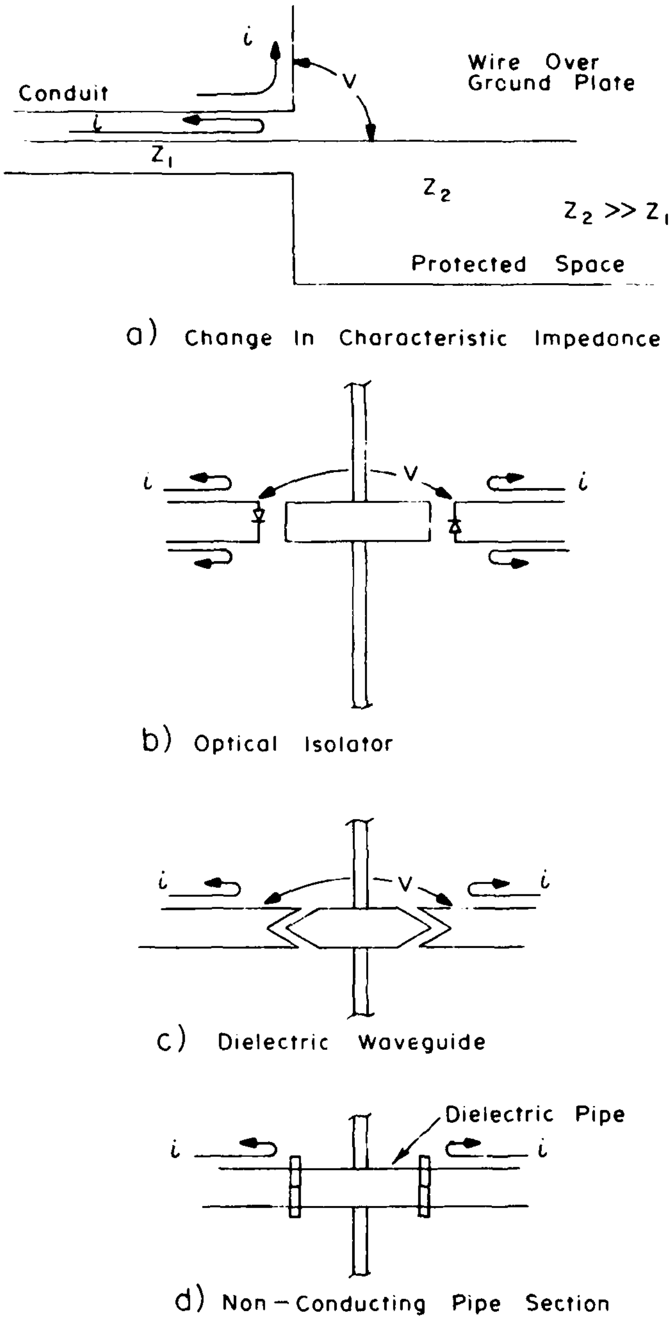

FIGURE 3. Current Reflection Techniques.

These latter devices are obviously limited in terms of their energy dissipation capability and often in their effectiveness at low frequencies.

2.2.2 Recommended Approach for Penetration of Shielding Associated with the RF Anechoic Facility

A requirement exists for providing a fire protection system for the RF anechoic facility. It is desirable to keep the gas bottles (Halon, CO2, etc.) outside the facility shield. Therefore, it is necessary to provide isolation on the fire sensor wires and gas transmission piping as it passes through the facility wall.

In terms of the concepts presented previously, either the current shunting concept, where the pipe is welded (or alternatively, threaded feedthroughs are used) to the facility shield, or the current reflection concept, where a non-conducting section of pipe is utilized, would be acceptable from a current-limiting consideration. However, the non-conducting pipe section has two major disadvantages: (1) the aperture created may result in significant emanations at UHF or microwave frequencies; and (2) the plastic pipe section could be destroyed by the fire. Therefore, it is recommended that the pipe(s) be conductive (steel) and be welded to the facility wall at the point of entry. In order to minimize the number of pipes which must penetrate the shield, it is recommended that distribution to the gas nozzles be performed internal to the enclosure. These internal distribution pipes can be situated between the shield and the RF absorbent material. The nozzles could be pop-out type so they also could be behind the RF absorbent until such time as they were operative. In this way these distribution pipes would not cause EM field disturbances (reflections) inside the facility and secondly would have less currents induced on them which could leak to the outside.

The fire sensor data lines must also be distributed throughout the facility and penetrate the shield for control. Inside

the facility they should be routed behind the absorbent material and inside the shield. At the point of shield penetration (ideally the same point as the pipes) they should be filtered. Since they are low frequency signals, a low pass filter should be utilized. It would be preferable to use an entry box as shown in Figure 2b. The filter enclosure could serve this requirement, but great care must be taken to insure that the filter case is well bonded (welded or soldered) to the facility wall so no leakage apertures are formed. To minimize pickup on the data wires themselves, it is recommended that shielded, twisted-pair wiring be utilized (i.e., balanced circuits with wire return rather than using the facility shield as the return or reference). This will require that the sensor reference be isolated from the facility shield (the sensor case if the sensor uses the case as the reference side).

This recommended treatment of the facility shield penetrations is depicted in Figure 4.

2.3 Considerations of Fire Protection Components on Chamber Performance

An anechoic chamber is intended to simulate free space by minimizing reflections of electromagnetic waves from the walls, ceiling, and floor. This is accomplished by lining the room with microwave absorbent material. One design concept is to place high quality (low reflectance) absorbent materials in the areas where single bounce reflections occur, with lesser grade materials employed to cover areas supporting double bounce (or higher order) reflections. In this manner the chamber can be designed to be very "quiet," in that measurements can be carried out in an area that simulates free space, i.e., reflection free.

Ray tracing, based upon geometrical optics, has been employed in the design of anechoic chambers and provides a means for illustrating the concepts used to select the most appropriate areas for locating components associated with the fire protection

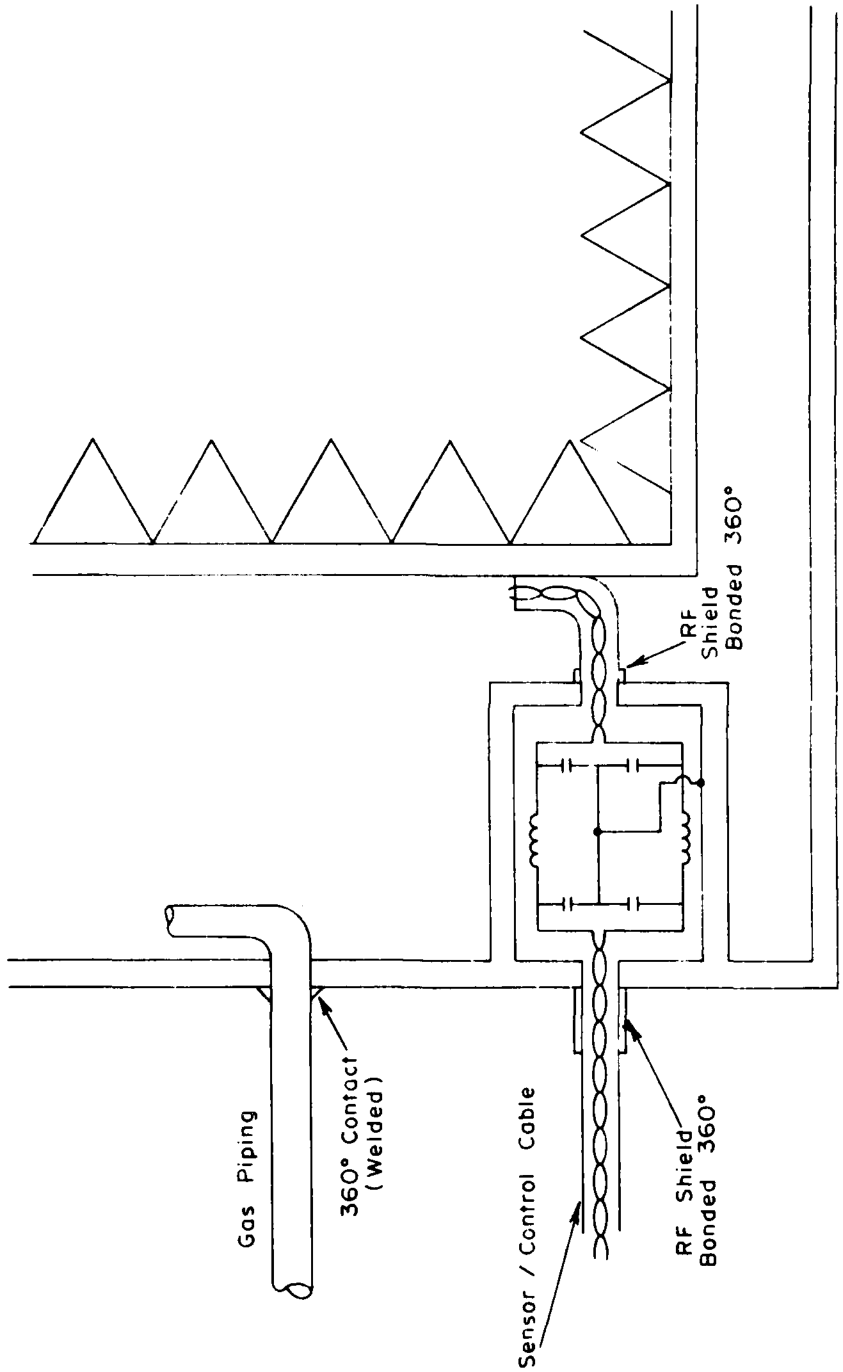

FIGURE 4. Penetration Entry Treatment.

system. Figure 5 contains a typical elevation or plan view of an anechoic chamber. The primary and secondary reflection areas are shown for the various paths in the principal horizontal or vertical planes containing the source and the receiver. The secondary reflections are double bounce, and experience energy absorption at each reflection area. Multiple bounce reflections supported by the wall/ceiling (floor) or ceiling (floor)/wall are also possible. Therefore, placement of any type of fire protection device should be avoided or minimized in the areas where primary or secondary reflections occur.

Figure 6 shows a three-dimensional view illustrating that the side walls, floor and ceiling constitute the primary reflection areas. These areas are related to the first Fresnel zone of the lowest frequency signal for which the chamber is designed to handle. Examination of these figures provide some insight into where fire protection devices are best located. The source wall, corners of the room, and areas away from the major axes of the room are regions where reflections are least likely to occur.

For practical use, it is necessary to install various instrumentation and fixtures in a chamber, which tends to degrade its performance (quietness). However, precautions are usually taken to minimize such degradation by placing absorbent materials around exposed reflectors or recessing them in the ceiling or floor. A few fairly obvious rules are followed in this regard. Metallic articles are not placed in areas where they can act as a single bounce reflector. Light fixtures and cranes are usually recessed or baffled to avoid direct reflections and fixtures are arranged to be out of the direct line of sight of either the source or receiver and/or covered with absorber.

Devices associated with a fire protection system must be treated in the same manner so that they will not degrade the chamber's performance. This is discussed in the following paragraphs.

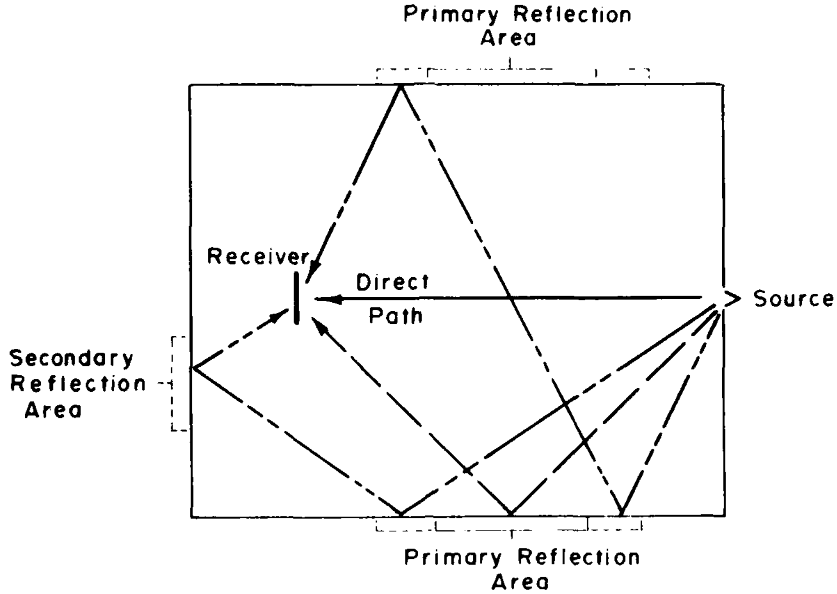

FIGURE 5. Reflections in Anechoic Chamber.

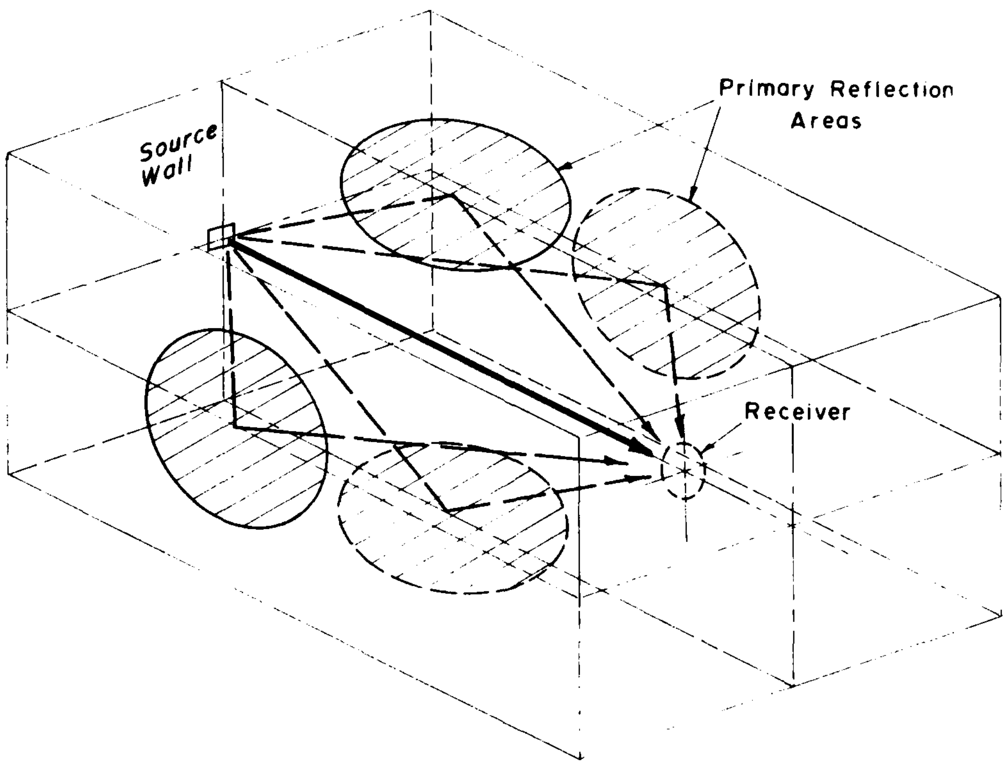

FIGURE 6. Three-Dimensional View of Chamber Primary Reflection Areas.

2.3.1 Suppressant Dispersion Nozzles

Whether a gas, water, or high-expansion-foam fire protection system is employed, an array of nozzles will be required to properly disperse the fire suppressant throughout the chamber. For good dispersion, nozzles should extend well into the chamber beyond the pyramidal peaks of the absorber material. Because of the historical practice of placing water sprinkler systems in the ceiling, it is generally taken for granted that any fire protection system will be placed there. This is not necessary in an anechoic chamber, since the walls are also available for placement of these devices and such an arrangement may provide efficient and effective coverage.

As stated, for optimum chamber performance, materials that reflect electromagnetic energy should not be arbitrarily placed in the chamber. This of course applies to the nozzles associated with the fire protection system; therefore, precautions must be taken in their design and placement. One approach is to employ nozzles made of a dielectric material to minimize any reflection they might produce. This technique has been used in the Electronic Warfare Anechoic Chamber located at Wright-Patterson Air Force Base. A Halon gas system has been installed in this facility with an array of nozzles in the ceiling for gas dispersion. Measurements of the chambers reflectivity made before and after the installation of these nozzles showed no discernable change. Therefore, this approach appears to have merit. The only criticism might be the susceptibility of this type of nozzle to damage by a fire.

Another approach is to employ metal nozzles of the pop-out type which telescope from a fairly short length to a length beyond the absorber pyramidal peaks. They would extend when the suppressant system is activated as a result of the pressure from the suppressant itself. In the inactive state, the collapsed nozzles would be located at the bottom of holes made in the absorbent material. Upon activation, the nozzles would extend

through the holes to discharge the fire suppressant. By proper positioning of the nozzles, they could be located in the valley of the pyramidal absorber structure, where they would produce the least reflection.

If the absorber material used is not thick enough to sufficiently shield the collapsed nozzle, they could be recessed into the walls of the chamber and the holes provided for their extension filled with a loosely fitting plug of absorber material that could be pushed out by the nozzle as it extends.

Either of these approaches would result in negligible chamber degradation and offers a means of implementing a fire protection system in microwave anechoic chambers.

2.3.2 Fire Detection Components

Reliable and early detection of a fire may require an array of fire detection components within the anechoic chamber. The same precautions discussed above must be exercised in regard to their location in order not to degrade chamber performance.

Air sniffers for smoke detection should be located behind the absorber material using either thin plastic tubing extending through the interior of the absorber pyramids and opening to the surface near the pyramid peaks or by employing a special section of open cell type absorber that permits air to circulate through it freely. This type of material is employed at the air intake exhaust ports of the chamber for heating and cooling.

Infrared and optical detectors can be located on the walls or corners of the chamber, again with the bulk of the device embedded within or behind the absorbent material. With only the sensor itself exposed, the area for possible reflections will be minimized. Again, by locating the sensors at the base of the absorber pyramids, they can be kept out of the line of sight of any active source in the chamber and prevented from acting as a primary reflection area. This may limit their field

of view to some extent, but it is considered to be a necessary precaution.

Active optical smoke detectors employing light beams should be located in holes made in the absorber since their field of view is usually very limited. Passive sensors could be placed in the corners of the room, a location that could provide complete coverage of the room and one that does not represent a source of single bounce (primary) reflection.

By using these general concepts for locating sensors in an anechoic chamber, i.e., avoiding placement where single or double bounce reflections between source and receiver can occur, little if any degradation in chamber performance will result from installation of fire protection equipment.

3. FIRE PROTECTION ENGINEERING CONSIDERATIONS

As reported earlier, the linings of RF anechoic chambers have the potential to support rapid fire development. In addition, the chamber and its associated equipment represent a sizable dollar investment. As a result, the selection of adequate fire protection is restricted to fully automated systems. Human interaction plays an important supplementary of "back-up" role but cannot provide reliable 24-hour, fast-response action that may be necessary.

3.1 Fire Protection Systems

To provide optimal benefit to the user, an automatic fire protection system must adequately perform several different functions. First, the system must reliably and rapidly detect fires while rejecting extraneous signals. Second, it must initiate an alerting signal recognizable by the facility occupants. Also, it must transmit an identifying signal to a responsible party and/or automatic suppression interface. (It may provide other functions as well.) Descriptions of these basic functions can be expanded as shown in Figure 7. To assure that these functions are reliably accomplished, the system should self-supervise its operability. Each detection/alert/alarm/suppression system performs these functions to a different degree. In the discussion to follow, the fire protection system will be treated as a fire alarm system (detection/control/alarm) interfaced with suppression. This grouping of actions is used to aid the discussion of particular subsets of the total fire protection system.

3.1.1 Basic Fire Alarm Systems

All automatic fire detection and alarm systems contain some form of sensor (detect function - see Figure 7) control/fire alarm panel (process function - Figure 7) and alarm device

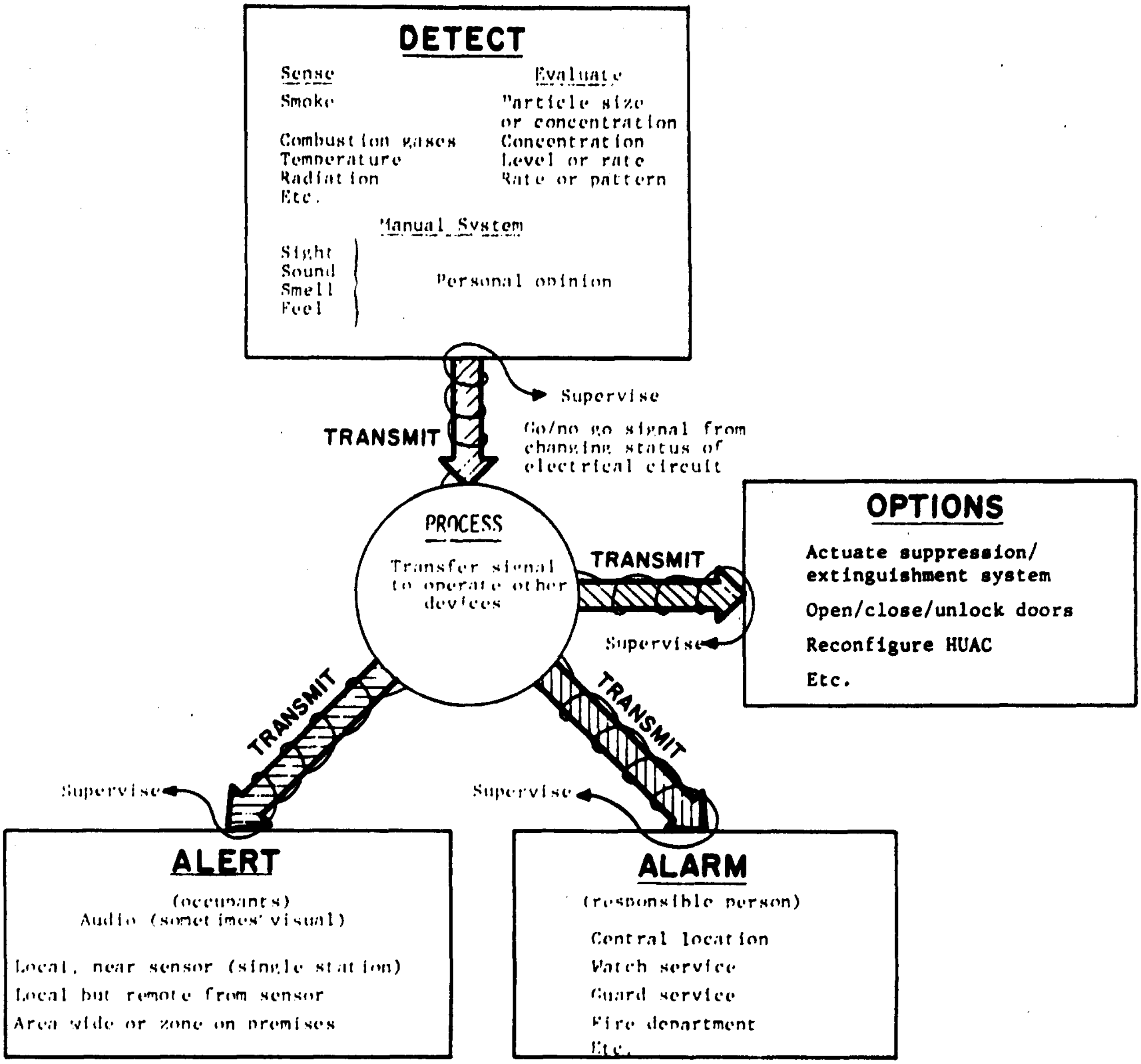

FIGURE 7. Functions of an Automatic Fire Detection and Alarm System.

(alert, alarm functions - Figure 7).* The simplest system is the single station detection device, which consists of a detector, a simple electronic or mechanical processor, and a bell or horn, all contained in a common housing. The single station system provides detect and alert** functions but does not provide alarm or optional control functions. Although occasionally used in industrial/commercial occupancies, usually small buildings, this system is generally considered a residential alarm. Studies (Refs. 19, 20, 21) have shown these systems, particularly versions employing smoke sensors, to be of significant benefit to the residential occupant.

The next step upward in system complexity physically separates the alert function from the detect and process functions. Again primarily for residential use, a horn or bell is placed close to the occupants' expected sleeping location and the processed signal delivered by hard wire or radio frequency transmission. Multiple station residential detectors offer a variation to this by interconnecting a series of single station detectors such that detection and processing by any unit causes all to deliver an alerting signal. Due to size and complexity of the facility, and desirability of automatically transmitting an alarm for outside assistance or initiating suppression, most automatic fire detection and alarm systems for industrial/commerical occupancies use more organized, elaborate hardware.

A central control panel generally is necessary to connect multiple detectors and audible alarm devices together at one point. The detectors in this use seldom contain internal bells or horns. Large buildings usually are divided into several zones of protection, and detection loops (separate circuits) are set

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* As was indicated in Figure 7, the manual pull station/fire alarm system indeed follows a similar pattern using the occupant as the detective device and requiring that he initiate the first transmit function.

** The term "alert" has been coined to describe the specific alarm function of notifying persons in the area of fire threat.

up within these zones to aid in identification of the general fire location. With this system, different methods of alerting personnel can be used to achieve the desired form of reaction. Critical circuits such as detection and alarm loops can be monitored (supervised) continuously to indicate system integrity. Several different automatic means of notifying the local fire services are available.

Automatic fire detection and alarm systems are traditionally classified by the method of transmission of a remote alarm and the nature of the "responsible person" to which it is transmitted. A brief description of these classifications is presented below.

(1) Local Fire Alarm System (Ref. 22) - internal (local property) alert only may interface with automatic suppression. Components of the system appear as a part of all other systems as well.

(2) Auxiliary Fire Alarm System (Ref. 23) - in addition to local alert (and perhaps suppression interface), a coded alarm signal is sent to municipal fire departments over municipally owned circuits.

(3) Remote Station Fire Alarm System (Ref. 24) - in addition to local action, a usually uncoded signal is sent along a direct connection to fire or police headquarters.

(4) Proprietary Fire Alarm System (Ref. 25) - in addition to local action, an alarm system is transmitted to a central supervising station at the property to be protected. Practical only for large facilities, since constant attendance is required at supervisory station.

(5) Central Station System (Ref. 26) - in addition to local action, a coded signal is sent over private, usually leased wires to a central office of a private company which then initiates appropriate action. The private company usually has direct-line voice communication with the fire department.

3.1.1.1 Control Unit

The control unit serves as the "brain" of any automatic fire detection and alarm system. It is the central device to which all subsystems are connected. The complexity required of the control unit is determined by the complexity of the system it manages.

3.1.1.2 Power Supplies

An adequate, reliable power supply has been shown through experience to be vital to any fire alarm system. A distinction is made between primary and secondary power supplies. The primary supply furnishes power for all signalling functions of the system. The secondary supply provides power to the system in the event of a failure of the main supply. The secondary supply also may provide power for trouble signals and other functions which are not essential for alarm transmission, but which are associated with system reliability.

The primary power source must demonstrate continued reliability under most conditions encountered at the protected property. The most common source used is that of the local electric utility. Usually batteries are charged from this source to be used as a secondary supply. Batteries must have the capacity to provide service for the period of time required by the applicable code, which could be as high as 60 hours.

A number of other acceptable primary and secondary supplies are acceptable under applicable NFPA standards.

3.1.1.3 Initiating Devices

A signalling system may provide indication, due to any or all of the following means of initiation:

1. manual (pull station)
2. automatic heat detection
3. automatic smoke detection
4. automatic detection of suppression equipment operation
5. automatic detection of abnormalities in industrialized processes or other conditions endangering life
6. "supervisory" signal of conditions which would prevent suppression system operation
7. voice communication

3.1.2 System Requirements

A "fire protection system" (detection/control/alert-alarm/suppression) must meet significantly more rigid requirements than a "fire alarm system" (detection/control/alert-alarm) due to the added suppression role. Automatic suppression is usually employed because of time constraints on manual action. Thus, failure of the system to actuate may leave no viable practical alternate action to preclude major losses. On the other hand, false alarms may be a nuisance; but, unwanted activation of a suppression system can be costly in terms of agent replacement, damage to protected property and lost time.

Grabowski (Ref. 27), on the basis of field experience, assigned a numerical value of one (lowest) to five (highest) to factors affecting the selection of "fire protection" or "fire alarm" systems. These are displayed in Table 3, which clearly indicates that added performance is required from a "suppression" system.

TABLE 3. Rating of Performance Required From Fire Alarm and Fire Protection Systems.

Performance Factor	Fire Alarm System	Fire Protection System
Sensitivity	4	4
Reliability	3	5
Maintainability	2	4
Stability	4	5

Grabowski's (Ref. 27) definitions of the performance factors, as applied to detection, are repeated below. These definitions can be readily generalized to apply to the system components.

SENSITIVITY - The sensitivity of the detection device is generally established by the physical design, except in the case of products of combustion units that can be adjusted. All of the thermal devices have fixed spacing ratings based upon the approval testing and the easiest way to increase sensitivity is

by reducing the spacing. This greatly reduces the response time to a fire and assures the application of the agent before extensive damage is done. Reduction in spacing is also recommended for the products of combustion units since reliance on the sensitivity adjustment alone can result in a false alarm problem. Sensitivity of the flame detectors is inherently high so this is not a major factor in equipment selection.

RELIABILITY - This factor is not normally considered for fire protection equipment and a requirement cannot be found in any standard, code, specification or approval requirement.* It is however, important that it be considered in automatic systems and worthwhile for discussion in this presentation.

Reliability relates to the ability of the system and each individual component to be in proper working condition at all times ready to perform its intended function. It has generally been misunderstood when occasionally referred to in fire detection as relating to the ability to repeatedly sense a fire. This actually is the stability of the unit rather than reliability. The aerospace industry has developed reliability to a point where it is incorporated in their system equipment specifications and their methods of analysis should be employed in the selection of the detection units. This generally has not been accomplished and it is only possible to present a general comment of the reliability of available detection units.

The units with the highest reliability are the fixed temperature eutectic units and rate compensated units. The simplicity of the eutectic devices gives it high reliability while the sealed construction of the other provides protection that allows the detector to withstand long service life under extensive conditions. The rate of rise units have a slightly lower reliability due to the more delicate nature of the sensing surface and possible failure of the rate function. All of the products of

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* Electronic circuit reliability is specified by the recently adopted UL 217 (Ref. 28), and the soon to be adopted UL 268 (Ref. 29).

combustion and flame detectors employ electronic components which have a higher failure rate than mechanical devices and result in a much lower reliability.

MAINTAINABILITY - The maintainability of detection units varies directly as the complexity of the design. The thermal units have no periodic maintenance requirements and the degree of maintainability with these units is extremely high. The products of combustion and flame detectors require periodic inspection and servicing to assure that the sensing element is in proper working order. This is not, however, an extensive effort and, therefore does not detract from these devices.

STABILITY - The stability of a detector relates to its ability to sense fires over extended periods of time with no change of sensitivity. This follows the general pattern of the other factors where the mechanical devices are better than the more complex electronic ones. In almost all the thermal units, there are no materials that have degradation of physical properties with age or usage while this is a known fact with electronic components. Periodic checking of all units with electronic components is necessary in view of this reduced stability.

The above analysis of existing detection devices is very general and the actual performance will vary depending upon the design, manufacture and quality control employed by the manufacturer. In all automatic systems, it is important that only those devices meeting the system requirements be used.

3.2 Problems of Automatic Fire Protection Systems

Problems with automatic fire protection systems which interface detection to suppression are generally related to the detection or control/alarm subsystems. Certain systems avoid many of the detection/control/suppression interface problems by mechanically linking detection to suppression. Examples of these are pneumatic rate of rise heat detectors linked directly to suppression valves, or, more simply, the fuseable link in an automatic sprinkler. In general, however, the detection device

provides or alters an electronic signal which is processed by the controller which then initiates alert, alarm, or suppression. Thus, although certain of the descriptions to follow pertain to "alarm" systems, the results can be applied to "protection" systems.

3.2.1 Fire Alarm Systems

Problems which arise with automatic fire detection/alarm systems fall into two categories: false alarm and failure to alarm. False alarms are by far the most common fault; however, the consequences of a failure to alarm are much more serious. False alarms are more of a problem with early warning fire detectors because of their inherent sensitivity. In fact, smoke detectors, for example, are normally manufacturer adjusted to a sensitivity setting well below their maximum capability as a tradeoff between false alarms and failure to alarm problems.

3.2.1.1 False Alarms

A survey of alarms transmitted from automatic detection systems to fire brigades in the United Kingdom showed that the ratio of total alarms to those alarms caused by real fires averaged 11 to 1 (ref. 30). The ratio for early warning (smoke) detection systems alone was even higher (see Table 4). These false alarms were attributed to:

- ambient conditions: 25 percent
- mechanical and electrical problems within the system: 48 percent
- failure or misuse of the communications portion (i.e., link to the fire brigade): 17 percent.

More complete information is presented in Table 5.

Sampling of automatic fire alarm calls in the Metropolitan Chicago area indicate the ratio of false alarms to real fires is considerably higher than in England and may exceed 50 or 100 to 1. Our experience also indicates there is a significant difference in the false alarm ratio depending on the type of smoke detection system installed. Offices, laboratories, plants and

institutions which have high quality (and expensive) smoke detectors appear to have much fewer false alarms than buildings installing a "compliance" grade system.

TABLE 4. Summary of Fire Calls Received by British Fire Brigades in 1968 (Ref. 30).

Type of System	Number of Calls to Fires: By System Installed	Number of Calls to Fires: By Other Means	Number of False Calls (System)	System Ratio: False Calls/ Fire Calls
All types	489	288	5440	11:1
Heat	193	105	2146	11:1
Smoke	101	37	1429	14:1
Sprinkler	101	125	1048	10:4
Manual	55	10	243	4:4
Mixed	18	6	137	7:6
Heat and Smoke	18	2	410	22:8
Unspecified	3	3	27	9:0

The onus of false alarms has led some regulatory and testing authorities to reclassify alarms caused by other than fire as false alarms and unwanted alarms. The term false alarm is used to describe an alarm caused by a malfunction in the detection and alarm system. The term unwanted alarm refers to detector actuation by some stimulus other than fire. This change in semantics can cause systems to appear more reliable than they really are. The effects of an alarm under nonfire related circumstances is the same whether we call it a false or an unwanted alarm.

Experience with early warning fire detection/alarm systems was analyzed using data from a large (over 5,000 employees) research and development facility and by random logging of automatic fire alarms transmitted to some local fire departments. The facility would be classified as a highly protected risk and had extensive (though not complete) smoke detector and automatic sprinkler coverage. The smoke detectors installed in this

TABLE 5. Reasons for False Calls From British Automatic Fire Alarm Systems in 1968 (Ref. 30).

Reported reason for false call	Total (all types)		Type of System							
	No	Percent	Heat	Smoke	Sprinkler	Manual	Mixed	Heat and Smoke	Gas	Unspecified
Totals	5441	100	2146	1429	1048	243	137	410	1	27
Ambient conditions (totals)	1410	25.9	561	631	55	8	12	137	0	6
Extraneous heat and smoke	951	17.5	306	523	24	3	5	87	-	3
High ambient temperature	233	4.3	180	10	15	1	2	25	-	-
Condensacion, snow, rain, etc	153	2.8	44	78	9	3	3	15	-	1
Low ambient temperature	37	0.7	16	6	5	1	2	6	-	1
Steam, vapor	29	0.5	13	10	2	-	-	3	-	1
Draught, high wind	7	0.1	2	4	-	-	-	1	-	-
Mechanical and electrical (totals)	2507	46.1	931	513	695	140	38	179	1	10
Defective wiring on control unit	602	11.1	258	153	97	26	17	49	-	2
Defective head	539	9.9	170	282	13	2	4	67	-	1
Surge in mains	411	7.6	12	-	392	2	3	2	-	-
Miscellaneous (e.g., broken pipe)	293	5.4	93	21	91	64	2	16	1	5
Direct impact on head	244	4.5	168	9	32	22	6	6	-	1
Vibration of system	215	4.0	109	26	38	15	2	25	-	-
Shock (e.g., by falling weight)	151	2.8	102	11	24	7	2	4	-	1
Voltage drop, power cut	42	0.8	17	8	6	1	2	8	-	-
Defective push button, etc	10	0.2	2	3	2	1	-	2	-	-
Communication (totals)	901	16.6	394	158	227	38	33	45	0	6
Testing, maintenance not notified	478	8.8	170	70	175	26	16	18	-	3
GPO activity	335	6.2	186	70	35	10	15	19	-	-
Defect in connection to brigade	88	1.6	38	18	17	2	2	8	-	3
Unspecified and unknown	623	11.5	260	127	71	57	54	49	-	5

facility are a particular, high voltage model which is considered by many to have a considerably greater reliability and freedom from false (or unwanted) alarms than common detectors sold for the compliance market.

During a one-year period, there were 74 alarms from smoke detectors. These resulted from:

1. burning of Class A materials	(3)
2. overheat or burnout of a component such as a capacitor or resistor in electronic equipment	(16)
3. overheating, smoking or failure in electrical wiring or equipment	(11)
4. people soldering or welding	(7)
5. persons smoking too close to detectors	(5)
6. electrical power outage or voltage dip	(2)
7. miscellaneous identified causes including: steam fork lift exhaust, dust, telephone company work, aerosol spray, etc.	(21)
8. unknown cause	(9)

Therefore, of the 74 alarms, three were definite fire, 11 represented a potential fire situation and 16 represented a possible but improbable potential fire situation. The remaining 44 alarms were associated with normal operations at the facility.

In addition to the smoke detector alarms, there were 215 telephone alarms for interior incidents.

fluorescent light ballasts - including odor, smoking, dripping and sparking	(137)
overheat or smoking of electrical equipment	(39)
flames in electrical wiring or equipment	(3)
smoking copy machines	(18)
nonelectrical fires	(13)
process overheat and smoking	(3)
mechanical overheat and smoking	(2)

It is commonly thought that smoke detectors have a higher false alarm rate than automatic sprinklers; therefore, the number of sprinkler alarms was also analyzed. There were a total

of 67 sprinkler alarms received; in three of these there was an inadvertant flow of water and in one there was an actual fire. The remaining 63 alarms would be considered false; a water surge was the most common cause.

The ratio of alarm to real fires was therefore between 2.5 to 1 and 5.3 to 1. It was also interesting to note that at this same complex, the ratio of automatic sprinkler alarms to real fires was 67 to 1. Although the automatic sprinkler head itself may be relatively free from "false" alarms, this does not appear true for the entire system.

3.2.1.2 Failures to Alarm and Delayed Alarms

The previously referenced British survey (Ref. 30) also indicated that automatic alarm system failures and delays were a small percentage of the real fires. Causes of these failures and delays were listed as:

- insufficient heat or smoke to actuate fire detectors
- disconnection or maintenance of system
- manual system operating before automatic
- failure of auxiliary or remote connections
- ventilation or currents at ceiling levels disrupting fire detector performance
- failure of automatic fire detectors
- failure of control equipment.

However, it is questionable if the first item - insufficient heat or smoke - can be considered a failure. That category problem identifies fires that were self-extinguished, and presented no threat or were detected first by the most sensitive detector of all, man.

Some alarm system failures may be a consequence of false alarm problems. Often after a number of false alarms a fire detection system will be disconnected or the sensitivity of smoke detectors may be adjusted so that response is limited to large fires.

On a previous program, Kemper Insurance (Longrove, Illinois) allowed IITRI to review their records for data which may be useful to this project. Information was received on impairments of fire alarm systems found by their Highly Protected Risk (HPR) division, consisting of approximately 6500 risks which are mostly of the industrial/commercial type. Data were compiled for two years, 1976 and 1977. Summaries of the data from alarm device impaired, reason for alarm equipment failure, circumstances upon discovery of impairment, and human causes of impairment are shown in Tables 6 through 9. Unfortunately, Kemper personnel were unable to relate the data to the total numbers of each type of system inspected.

From these data, it is seen that the most common alarm failure scenario is a water flow alarm switch malfunctioning upon test due to improper adjustment or setting. It should be emphasized, as mentioned in Tables 8 and 9, that special extinguishing systems contributed only 2 percent of impairments, and were not even included in the data sample.

Many of the false alarm and equipment failure problems presented above can be minimized by a proper maintenance program. All of the standards require maintenance at 6-month intervals in most cases. NFPA 72B and 72C specifically refer to a contractual agreement which implies that it is preferred that an outside firm of some kind be utilized. NFPA 72C (Ref. 24) requires filing of reports with the authority having jurisdiction, when required. NFPA 72E (Ref. 31) requires smoke detector checks, which are to be done every 6 months, to be kept on file for a minimum of 5 years. Pull stations are to be activated at least every 6 months, and according to NFPA 72C, should be done on a monthly basis. Transmission equipment should be inspected and activated on a monthly basis. Heat detectors of the restoreable type should be tested initially. Heat detectors of the fixed, nonrestoreable type do not have to be tested, much like a sprinkler fusible link. Water flow alarm devices should be tested in accordance with the standards by simulating as closely

TABLE 6. Discovered Impairment of Security or Protective Signaling Service.

Alarm System Equipment Involved	Central Station Signaling Service	Proprietary Signaling Service	Auxiliary Protective Signaling Service	Remote Station Signaling Service	Local Protective Signaling Service	Total
Water flow switch	124	52	10	27	22	235 (37.5%)
Valve tamper switch	151	9	0	6	8	174 (27.8%)
Automatic fire alarm	8	0	1	0	4	13 (2.1%)
Supervisory signaling device - N.O.C.*	19	1	0	2	3	25 (4.0%)
Firm alarm box	3	1	8	1	3	16 (2.6%)
Burglar alarm	2	0	2			4 (0.6)
Transmission devices	37	11	3	17	0	68 (10.9)
Transmission lines	41	6	1	5	1	54 (8.6)
Signal rec. and recording equip. failure	1	2	0	4	3	10 (1.6)
Retransmission failure equipment	1	0	0	1	0	2 (0.3%)
Retransmission failure human	3	0	0	1	0	4 (0.6%)
Not applicable	1	0	2	0	0	3 (0.5)
Other - N.O.C.	7	2		3	6	18 (2.9)
	398	84	27	67	50	626(100.0%)

* N.O.C. - not otherwise classified

Note: While failures under water flow switches and valve tamper are numerous, there were actually more failures than shown. Per Kemper guidelines, where multiple incidents of this type are found at a plant, they are reported on a single impairment report.

TABLE 7. Reason for Alarm Equipment Failure.

Alarm System Equipment and Reasons for Failure	Central Station Signaling System	Proprietary Protective Signaling System	Auxiliary Protective Signaling System	Remote Station Signaling System	Local Protective Signaling System	Total
Transmitter run down	6	1	2	1	0	10 (1.59%)
Improper adjust/setting	127	14	2	14	12	169 (26.95%)
Contact corroded, dirty welded	46	15	2	7	2	72 (11.48%)
Removed from service (HPR not notified)	29	2	2	2	8	43 (6.86%)
Disconnected conductors	60	13	3	7	6	89 (14.19%)
Not applicable	8	0	0	0	3	11 (1.75%)
Other - mechanical	72	12	7	10	5	106 (16.91%)
Other - electrical	36	16	9	23	13	97 (15.47%)
Unknown	11	11	7	0	1	30 (4.78%)
	395	84	34	64	50	627(100.00%)

TABLE 8. Circumstances Upon Discovery of Total System Impairment.

Impairment Type	Alarm Equipment	Closed Valves	Sprinkler Equipment	Water Supplies	Total
Total Number of Impairments	635 (58.3%)	246 (22.6%)	91 (8.4%)	117 (10.7%)	1089 (100.0%)
1. Work in progress	10 (1.57%)	26	15	17	68
2. Work done forgot to restore	10 (1.57%)	57	1	6	74
3. Removed from service (HPR not advised)	30 (4.72%)	27	22	8	87
4. Know, no specific active to restore	22 (3.46%)	22	12	8	64
5. Management unaware of impairment	82 (12.9%)	102	8	31	223
6. Equipment malfunction on test	468 (73.7%)	3	29	40	540
7. Other - N.O.C.	13 (2.05%)	9	4	8	34
TOTAL of Items 2,3,4,5 (See Note 1)	144 (32.1%)	208 (46.4%)	43 (9.6%)	53 (11.8%)	448 (41.1%)

Note 1 - Total of Items 2, 3, 4, 5, represents impairments due to lack of adequate management control and awareness (potential negligence)

Note 2 - Special Extinguishing Systems, constitutes only 15 (2%) of impairments, and other electrical constitutes only 28 (4%) of impairments, and are not included in these statistics

TABLE 9. Act of Person Causing Impairment.

Impairment Type	Alarm Equipment	Closed Valves	Sprinkler Equipment	Water Supplies	Total
1. Plant personnel	43 (12.3%)	154	43	31	271
2. Contractor personnel	20 (5.73%)	37	4	3	64
3. Alarm company personnel	106 (30.37%)	2	0	0	108
4. City or public works personnel	11 (3.15%)	15	0	5	31
5. Noninsured building or tenant	2 (0.57%)	1	0	0	3
6. Not applicable - i.e., equipment failure	143 (40.97%)	6	19	35	203
7. Other - N.O.C.	13 (3.72%)	7	4	10	34
8. Unknown	11 (3.15%)	24	1	2	38
	349 (46.4%)	246 (32.7%)	71 (9.4%)	86 (11.4%)	752

Note 1 - Special Extinguishing Systems constitutes only 15 (2%) of impairments, and other electrical constitutes only 28 (4%) of impairments, and are not included in these statistics

as possible, a real water flow test. Line type detectors of the nonrestoreable type should not be heat tested but should be carefully checked for faults or grounds. At the far end of the circuit, the wires should be shorted to check for signal transmission.

A host of devices, of varied practicality and sophistication, have been used to check automatic detection devices. The most elementary heat detector testing device has ranged from a hot bucket of water and a sponge, to a butane lighter, to a special cone shaped device with a heater element. The elongated rate compensation detectors can be checked with a soldering iron with tip removed (slips over the barrel). Flame detectors are tested with a UV flashlight. Some sophisticated flame detection systems have internal testing mechanisms which duplicate a flame with built-in UV tubes in each detector.

The largest variety of testing devices and methods are those associated with smoke detectors. Some are elementary, such as a man on a ladder blowing cigarette smoke at a detector. As unsophisticated as that may seem, until recently it was the only way to activate certain detectors. Another method often seen is a length of conduit with a piece of smoldering sash cord introduced at one end. Raising the smoldering cord to the detector location, and blowing through the pipe directed particles of combustion toward the detector. One manufacturer has recommended this in their manual. Other manufacturers produce electrical devices specifically designed to test their detector electronics. Small smoke chambers and small box assemblies have been devised by some manufacturers whereby installers can introduce a burning punk and measure percent obscuration/ft at alarm. Some detectors are now appearing with a test feature which allows either a mechanical or magnetic simulation of smoke in the chamber.

The newest field test device to enter the picture is called an aerosol particle generator (Ref. 32). This device allows test of smoke detectors regardless of type or manufacturer in a

repeatable manner. Alarm response is read in terms of percent obscuration/ft. By atomizing a solution of dioctal phthalate, the device exposes the detector to a particle distribution similar to that in the UL 217 sensitivity test. This provides the responsible party with documentation never before available, and can indicate if a detector is becoming overly sensitive or losing sensitivity.

Various control panel components, such as relays, capacitors, resistors, diodes, and transistors require occasional maintenance by a competent technician. Batteries, battery chargers, lamps, fuses, circuit breakers, etc., require periodic checking.

The field wire between the control unit and the various devices connected to it will require little maintenance if it was properly installed. Improper installation or water in the conduit from an accidental overflow in a tank, drain, etc., can cause ground faults. Open faults in the wiring can be caused by improperly stripping the insulation at terminal points, causing deep nicks in solid conductors which later break at the terminal points from vibration or handling.

3.2.2 Suppression System Interfacing Factors

Actuation of fixed fire suppression systems by automatic detection systems generally involves processing and transmitting a signal that opens some type of valve. The valve opening may release the suppressant directly or it may pressurize the suppressant container and cause it to discharge. The valve may be a conventional type operated electrically, mechanically or pneumatically, a deluge type valve opened mechanically or by fluid pressure, or a frangible diaphragm which is mechanically, explosively or pneumatically ruptured. In some combination of circumstances and systems, actuation of suppression systems by early warning detectors is highly advantageous; in others, it may be neither desirable nor of any benefit.

The most common types of detector actuated suppression systems are:

1. Water Deluge System - An array of normally open single heads or spray nozzles with a common water supply control valve; opening of the valve, manually or automatically, supplies water to all the sprinklers or nozzles simultaneously.
2. Foam/Foam-Spray - Similar in actuation to a water deluge system. Foam concentrate is mixed into water, and air is aspirated at the nozzles to generate foam; may be applied in the pattern of conventional sprinklers or in spray patterns.
3. Foam-Water/Foam-Water Spray - Similar to Item 2 except the nozzles can discharge either foam or water; agent can be selected manually or if foam supply is exhausted, water will continue to be applied; may or may not use air aspirating nozzle.
4. CO_2 - Open nozzles supplied from storage through a manual or automatically actuated valve; CO_2 supply may be either high pressure cylinders or low pressure refrigerated storage.
5. Halon - Similar to Item 4 except agent is Halon 1301 or 1211.
6. Dry Chemical - Open nozzles supplied from container; agent is expelled by N_2 pressure supplied by high pressure cylinders.
7. High Expansion Foam - One or more generators are used to flood an entire volume with a 600:1 to 1000:1 expansion ratio foam. That is, the water will occupy 600 to 1000 times its original volume.

3.2.2.1 Detector Operated Suppression System False Alarms

Consequences of false (or unwanted) alarms are greatly increased when the detection and alarm system also operates a fixed fire suppression system. Discharging fire extinguishing agents can be expensive in terms of damage done and/or the cost of the agent. At times, such a discharge can directly or indirectly imperil personnel. Discharge of water, foam or dry chemical agents may damage contents and building services; personnel can easily be injured by falling on slippery surfaces under decreased visibility. The clean agents, CO_2 and Halon, are less likely to damage contents but CO_2 can suffocate people and Halon may injure persons with heart problems (Ref. 33). The

cost of the agent itself may be high, particuarly Halon 1301. There are large installations where the cost of recharging a system exceeds $30,000. The costs and risks of agent discharge are acceptable in a fire situation because the potential fire loss is much higher.

The problem of inadvertent operation of suppression systems by smoke detection has been satisfactorily resolved only in some relatively sterile environments such as computer rooms. Heat detector actuation of suppression systems has been successful in many locations; actually an automatic sprinkler system is really a suppression system operated by a relatively insensitive fixed temperature heat detector.

Smoke detector actuated suppression systems have very few current applications and require very careful design to minimize inadvertent operation. Almost every such system requires operation of two detectors to discharge the suppressant and includes provision for manual abort. Some systems are wired in a cross zoned arrangement where a detector in each of two criss-cross zones must actuate before the suppressant is discharged (see Figure 8). Another circuit arrangement is known as priority matrix which requires actuation of two adjacent sensors before the suppressant is discharged (Figure 9).

Heat detector actuated suppression systems can be used in many locations; however, only in a limited number of circumstances do they offer any advantage over a less costly and more reliable automatic sprinkler system. The principal use of such systems is in locations where a very rapidly developing fire is likely or where water cannot be used for suppression. The anechoic chamber may well fit this description.

In new installations of any detector actuated suppression system it is common to put the detection system in service for one or more months before connecting it to the suppression system. This permits identification of unanticipated false alarms and corrections can be made, or the concept advanced, without unnecessary and costly suppressant discharge.

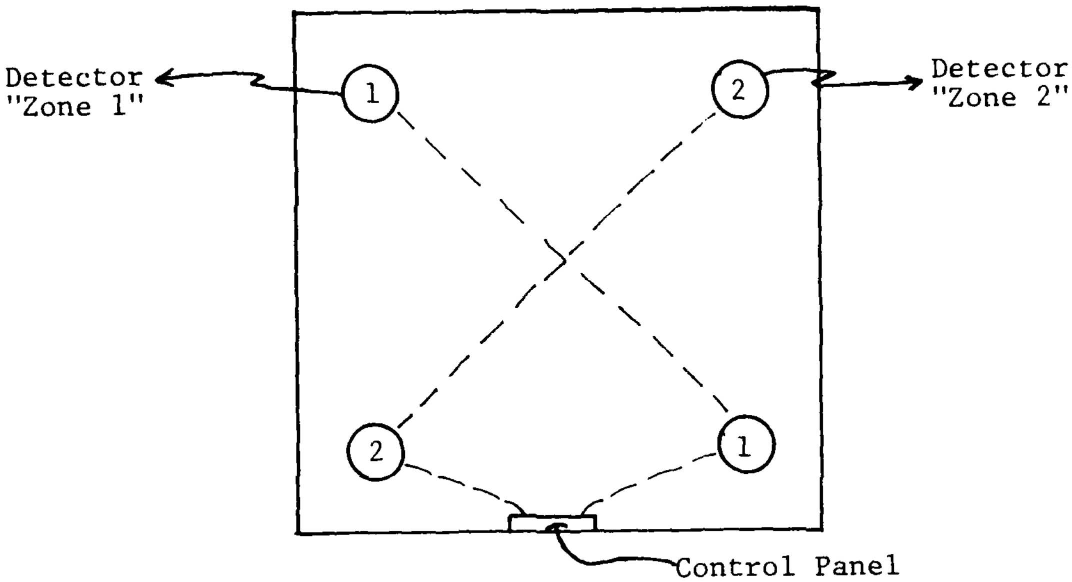

FIGURE 8. Cross Zoning.

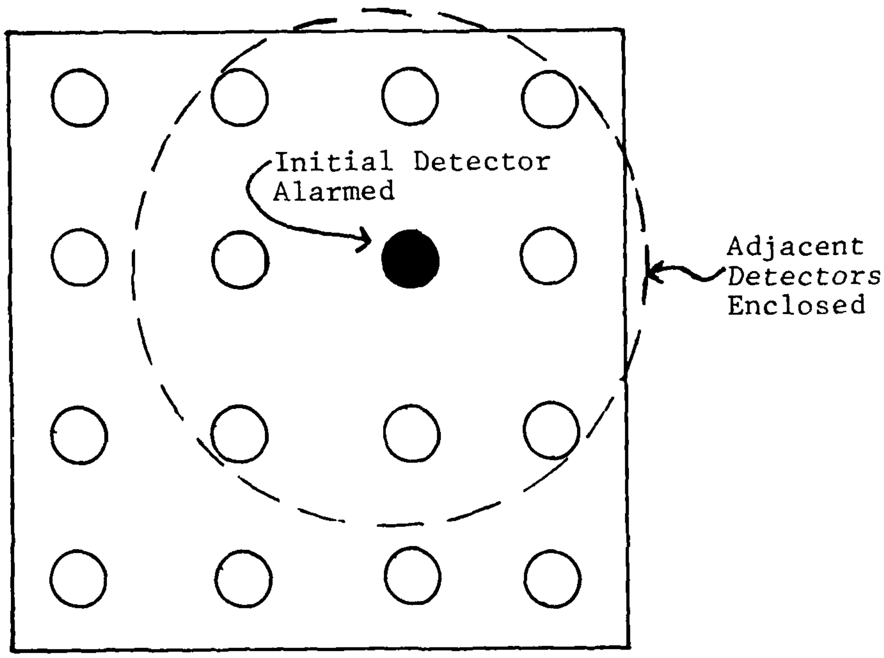

FIGURE 9. Priority Matrix: Overall Alarm Activation by Alarm of Detector Adjacent to Initial Alarming Detector.

3.2.2.2 Suppression Failures and Delays

Certainly, if a suppression system fails to work at all or actuates too late, the unprotected risk will be damaged or destroyed. In some cases a failed system is worse than no system at all, for occupants begin to take for granted the automatic system and do not react properly in a system failure situation.

Systems failures or delays are usually related to problems with detection or the agent release device. There is very little information on the reliability of the latter.

3.2.2.3 Personnel Safety

Personnel may be endangered by the release of suppression agents in response to either real or false alarms. Various techniques are employed to minimize adverse effects of suppressant discharge on personnel. Certain of these techniques permit "saving" the automatic system agent when it is obvious that the fire will be quickly suppressed by manual means. Audible alarms sounding concurrent with suppression activation are often sufficient warning for systems such as water spray devices or small systems within cabinetry or machinery. Where a "total flooding" CO_2 system is employed, it is necessary to provide a prealarm followed by a time delay for suppressant release, thus permitting evacuation. Halon systems may be used for "total flooding" up to a 7 percent concentration without a prealarm/time delay sequence. This concentration is effective against surface fires. Deep seated fires require higher concentrations which can be achieved as a "second step" once personnel are evacuated. Manual overrides are generally provided for these systems so that the sequence may be interrupted should manual suppression be possible. When maintenance, repair or other activities in the protected workplace put personnel in unusual predicaments requiring longer evacuation times, it is common to "lock out" the system with the manual override control. This practice can lead to inadvertent system disablement for long periods and expose the worker to increased fire hazard without proper administrative procedures and control.

Safety hardware associated with the various types of suppression systems are described, and required by the NFPA standard applicable to the system, e.g., NFPA 12, Carbon Dioxide Systems, etc.

3.2.3 Human Reliability in Fire Alarm Systems

3.2.3.1 Requirements for a Satisfactory Fire Protection System

Changes in technology levels and a continuing need to optimize systems for cost effective or efficient operation have produced increasingly sophisticated manufacturing and industrial process systems, and greatly increased capital investment. The possible consequences of fire and the opportunity for reducing losses through fire protection systems has generated keen interest in quantifying fire protection system effectiveness. However, until recently, fire protection systems have been considered as hardware systems without recognition that the function of the system is not completely realized until human response is integrated.

Early alarm systems were no more than a thermoswitch connected to a bell on the wall. Once turned on, they were supposed to operate forever with 100 percent reliability. People were supposed to be similarly perfect at recognizing and responding to the alarm. Today, we can show that such cases are the exception and not the rule. Fire alarm systems generate false alarms, and fail to alarm; and, people incorrectly interpret the signals and respond inappropriately.

A reassessment of the extent to which existing fire response systems can be upgraded and made optimally safe is necessary. An important part of this assessment is a requirement for accurate identification of the contribution of man, machine, and environment variables to system failure. Historically, large improvements in system reliability have been realized by offsetting the shortcomings of either man or machine by capitalizing upon their often reciprocal relationship in abilities. As shown in Table 10, their complementary characteristics can often yield

TABLE 10. Areas of Ability in Which Man-Machine Tradeoffs May be Made.

Assigning Work to Man and Machine	
Man Excels in	Machine Excels in
Detecting certain stimuli of low-energy levels	Monitoring (both men and machines)
Sensing an extremely wide variety of stimuli	Performing routine, repetitive, or very precise operations
Perceiving patterns and making generalizations about them	Responding very quickly to control signals
Detecting signals in high-noise levels	Exerting great force, smoothly and with precision
Storing large amounts of information for long periods and recalling relevant facts at appropriate moments	Sorting and recalling large amounts of information in short time periods
Exercising judgement when events cannot be completely defined	Performing complex and rapid computation with high accuracy
Selecting own inputs	Sensitivity to stimuli beyond the range of human sensitivity (such as infrared, radio waves)
Improvising and adopting flexible procedures	Doing many different things at one time
Reacting to unexpected low-probability events	Reasoning deductively - going from general to specifics
Applying originality in solving problems: i.e., coming up with alternative solutions	Being insensitive to extraneous factors
Profiting from experience and altering course of action	Operating very rapidly, continuously and precisely the same way over a long period
Performing fine manipulation, especially where misalignment appears unexpectedly	Operating in environments which are hostile to man or beyond human tolerance
Continuing to perform even when overloaded	
Reasoning inductively - specifics to general	

a far more reliable system in which the man is happier with his role and where productivity, reliability, and quality of product are improved.

The greatest attention to optimization of these relationships has been in areas where less than perfect performance is not acceptable, regardless of cost. Aircraft, defense weapons, and aerospace systems can all fail catastrophically and, aside from their cost of production or replacement, often exist in "one of a kind" configurations or fulfill a requirement imperative to the survival of large numbers of people. The critical nature of the mission has caused these systems to be studied extensively to assure that the best man/machine match possible is obtained, and reduce failure due to trivial mismatches or mistakes. Failure of high energy systems or those in which the release of energy through fire cannot be reliably terminated or controlled yields disasters which can and have been every bit as costly as failure of a weapons system. The objective of fire protection system development must be to assure that an acceptable level of reliability is obtained and maintained at a cost commensurate with the benefits. Similarly, tradeoffs between the development of improved fire alarm systems and improvement of the potential source of fire must be made.

A brief listing of the variables that most frequently affect human performance is presented in Table 11. These performance shaping factors all contribute to the probability of an individual correctly installing, operating, maintaining, and responding to a fire protection system.

A variety of alternatives for improving system reliability are usually identified as a part of a cause identification analysis and a subsequent review of cost effective measures. Representative areas for treatment may include:

- rules and regulations,
- enforcement practices,
- hardware changes,
- education and skill development, and
- system changes.

TABLE 11. Variables Offsetting the Reliability and Probability of Task Performance.

Performance Shaping Factors	
Extra-Individual	Intra-Individual
Situational Characteristics	Psychological Stresses
Temperature, humidity, air quality	Task speed
Noise and vibration	Task load
Degree of general cleanliness	High jeopardy risk
Manning parameters	Threats (of failure, loss of job)
Work hours/work breaks	Monotonous, degrading, or meaningless work
Availability/adequacy of supplies	Long, uneventful, vigilance periods
Actions by supervisors	Conflicts of motives about job performance
Actions by coworkers and peers	Sensory deprivation
Actions by union representatives	Distractions (noise, glare, movement, flicker, color)
Rewards, recognition, benefits	Inconsistent cueing
Organizational structure (e.g., authority, responsibility, communication channels)	
Task & Equipment Characteristics	Physiological Stresses
Perceptual requirements	Fatigue
Anticipatory requirements	Pain or discomfort
Motor requirements (speed, strength, precision)	Hunger or thirst
Interpretation and decision making	Temperature extremes
Complexity (information load)	G-force extremes
Long- and short-term memory	Atmospheric pressure extremes
Frequency and repetitiveness	Oxygen insufficiency
Continuity (discrete vs continuous)	Vibration
Feedback (knowledge of results)	Movement constriction
Task criticality	Lack of physical exercise
Narrowness of task	Individual (Organismic) Factors
Team structure	Previous training/experience
Man-machine interface factors: design of prime equipment, job aids, tools, fixtures	State of current practice or skill
Job Instructions	Personality and intelligence variables
Procedures required	Motivation and attitudes
Verbal or written communications	Knowledge of required performance standards
Cautions and warnings	Physical condition
Work methods	Influence of family and other outside persons or agencies
Shop practices	Group identifications

The latter are intended to eliminate the occurrence of high risk situations in normal routines or provide suitable alternate means of avoiding the situation. Families of solutions are frequently defined with the best combination of treatments selected as appropriate based upon sensitivity analysis and cost effectiveness results. Figure 10 presents some hypothesized levels of remediation obtained from the application of several possible treatments. As an example, a new regulation may result in substantial improvement initially with some deterioration unless enforcement and continuing awareness of the regulation are achieved. Education and skills training may require a greater amount of time until the entire user population is brought to a given level of competence. Education and training programs are also susceptible to effects from turnover and failure to provide updated information or practice. An improved hardware design could provide improvement in reliability; however equipment in the field must either be retrofit or replaced with the improved designs according to a consistent schedule. The curves in Figure 10 are hypothetical and may or may not apply to a specific situation. Several types of effects are observed with the remediations shown, i.e., rapid improvement with gradual deterioration, steady improvement to an asymptote, or steady improvement with no fixed limit until 100 percent compliance is obtained.

3.2.3.2 Field Experience Gained From Alarm Systems

Information on alarm systems consists largely of studies directed toward specific problems or specific user populations. Of greatest concern has been the protection of life in large institutions. Experimentation with different systems has been very limited and empirical demonstration of the superiority of a given type of system does not appear to have been presented.

The problems in the development of adequate alarm systems may be categorized as those associated with:

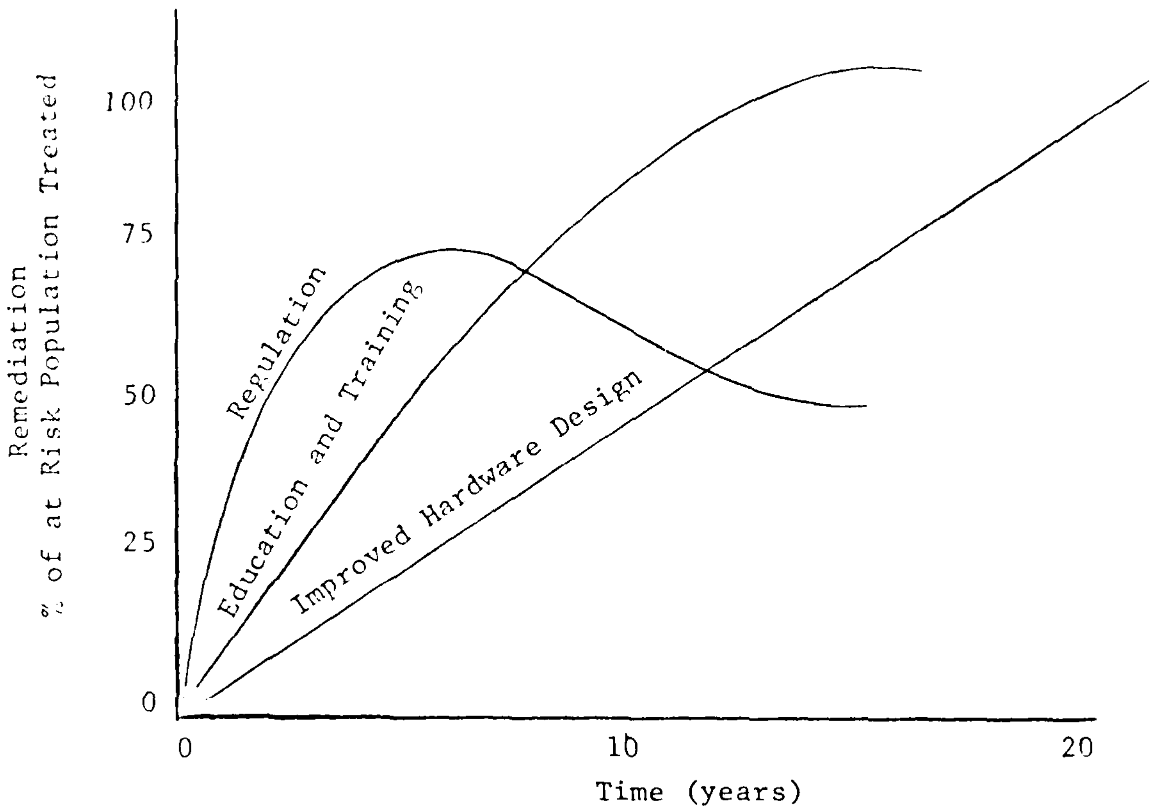

FIGURE 10. Comparison of Benefits of Implementing Several Different Accident Remediations.

- arming and disarming the system,
- maintainability,
- human response to alarms, and
- system expansion and alteration.

A field study recently performed in nursing homes (Ref. 34) yielded qualitative information in each of these areas which is applicable to this report. The problems identified represent generic classes of problems likely to be encountered in most alarm systems.

Arming and Disarming: The ability of staff and engineering personnel to trigger the alarm, reset it, and verify that an alarm has been transmitted beyond the borders of the affected institution is frequently lacking. Repeatedly, administrative, professional, and engineering staff have difficulty in setting off the alarm. In some instances it was assumed that manual pull boxes did not trigger immediately. If a special test switch is provided in the system, instances were found where none of the staff charged with responsibility for conducting tests and drills, other than the plant engineer, were aware of its presence. Similarly, instructions for operation of the system and identification of the points alerted in case of an alarm were lacking. Familiarity with the system was often based upon word of mouth (apparently derived from original instructions by the installer) or by hand written notes the administrator or fire safety supervisor had made on the basis of experimentation. Triggered alarms frequently could not be reset (in some cases the system had to be deactivated until an engineer or service man could be obtained).

In one facility, recently installed smoke detectors varied excessively in sensitivity so that some would trip with very little visible smoke while others failed to respond to much heavier smoke. Obviously, if the fire department were hardwired into the system, false alarms would be a persistent problem. In one instance, smoke detectors were wired as a separate system which notified an internal monitor. Detector information was

then compared with visual verification and/or information from other sources before the fire department was notified. The delay in response was apparently preferable to the unacceptable false alarm rate.

Maintainability: Maintainabilty of these systems is concerned with system design that permits them to be regularly tested by the people at hand to assure functionality and that permits prompt return to operational status. A highly maintainable system will provide positive feedback concerning operational status, and in the event of a fault, will provide an unambiguous description of the locus and type of fault. Troubleshooting, repair and restoration to an active state must be practicably attainable tasks without the necessity to resort to specialized information, tools, or facilities if anything approaching a useful system is to be designed. In field tests, numerous alarms were found which either failed to operate, operated in a feeble or erratic manner, or failed during a one minute test. Failure modes ranged from never having been electrically connected in the system, to alarms completely covered with many coats of paint which effectively damped the sound output and radically altered the tone of the alarm. In no instances were instructions for testing and operation found which could be deemed adequate for understanding by the personnel charged with fire alarm maintenance and operation. In many instances a plant engineer was found who was knowledgeable in the details of the system and its operation and maintenance. However, the plant engineer is usually not responsible for the overall fire safety plan and is often not present when fire drills or tests are to be conducted. Under the best of conditions an engineer was only available during the work day, and in many instances, his duties were shared among several buildings or institutions. In other instances, a fire alarm service was contracted; however, the service could not be readily located or, in one instance was out of business. Another service allegedly contracted by one of the institutions claimed that it was not a customer although it may have been at one time. In short, the primary maintainability effort for

these fire alarm systems apparently consisted of the visits of a state inspector. The reports or records of these visits were similarly difficult to ascertain from institution sources. Interviews and questionnaires with support staff generally indicated an awareness of in-institutional drills only, which may not be an accurate reflection of actual testing performed. It was apparent that those institutions with written procedures, regularly scheduled weekly tests, and a specified fire safety supervisor were capable of testing the system more rapidly and reliably than in institutions with a less formal test arrangement.

Human Response: The problem of human response to an alarm system consists of two distinct parts. Initially, the subject must be capable of accurately identifying the alarm as being fire related. With this information in hand, he must be aware of the correct response or family of responses and be capable of initiating these in an acceptable order. Of the facilities examined during the field experimentation described earlier, many difficulties in identifying the source and meaning of the alarm were observed. Confusion existed between the fire alarm, elevator alarms, annunciator signals, boiler low water alarms, and emergency door alarms. Facilities having frequent tests of the alarm system appeared to have less difficulty in this area than those with infrequent familiarization tests. The latter group would more closely approximate the general experience of people using industrial and commercial alarm systems.

With regard to the selection of the appropriate response to an alarm, a study of 400 staff members (including all occupations in long-term health care facilities) showed a large disparity in selection of appropriate fire alarm responses. Some differences were attributable to the plan design by the fire safety supervisor; however, most differences were a result of training deficiencies.

A very significant problem in fire response is that of preventing uninvolved parties from participating and degrading the situation by either adopting inappropriate extinguishing or containment tactics or by exposing additional people and materials to the hazard. A common problem in health care facilities, during a fire, is that of visitors attempting to lead groups of patients out of the building. In practice, the safest procedure, initially, is to keep all people in the rooms with the doors shut. Staying away from the vicinity of the fire can then be controlled while smoke exposure is held to a minimum. Disasters have been developed from comparatively small incidents when visitors opened the door to the room with the fire in an attempt to either clear smoke or fight the fire. The smoke immediately fills all open spaces from the ceiling downward causing injury and death as well as promoting fire spread through the opening. Similar consequences followed people leading groups through a smoke filled area when they could have remained in a safe area.

In summary, one of the greatest problems in alarm system reliability is the bridge between the sounding of an alarm and the execution of the appropriate response in a timely manner by the appropriate people. Recognition of the alarm as an indication of fire as opposed to false alarm or no indication of fire is a prerequisite. We have found significant numbers of people who could not perform reliably at this level of interpretation. If a correct identification has been made, the selection of the appropriate response is similarly problematical. If the appropriate response is selected it is possible that the individual does not know how to perform it (such as calling the local fire department or obtaining assistance), and if the appropriate response is made it is not unusual for misinformed or uninformed individuals to completely undo the effort and exacerbate the situation.

An important aspect of fire response not directly addressed above is communication of desired activities between persons. Observed during field tests were a number of situations where

the sound level of the alarm was so great that speech was effectively masked preventing staff-resident communication and causing considerable disturbance and delay. In one instance, the noise level exceeded 113 dB, an intolerable noise level. Consideration must be given to adequate means of disarming the system once a fire identification has been made or to adequate means of permitting communication while the alarm continues to sound. The continued presence of a fire alarm during drills and firefighting activities, like noise introduced as a stress or in the performance of complex tasks, will significantly degrade the reliability of the people performing the tasks.

System Expansion and Alteration: Nearly all fire alarm systems are eventually modified to suit changing manufacturing or service requirements. The addition of new alarms or subsystems often present problems in electrical and mechanical compatability but, as important, often compound the difficulty of recognizing or distinguishing the fire alarm system from other alarms and warning devices. As an example, it is not uncommon to find one portion of a building alarmed by a bell system while another portion of the same system uses vibrator horns and a third section uses chimes. The type of alarm indicating fire must thus be associated with location. Another significant difficulty with the system is that frequently the electrical interface has not been adequately designed and tested. In one instance, a facility had operated for a number of years with the assumption that an existing detector/alarm system for staff dormitories was interfaced with the newer system as requested and from there directly to the fire department. Testing demonstrated that no electrical interface between the two systems had been made. Similarly, installers of new alarm system components often do not test the entire system, either because of a lack of information about how to operate it or because of a reluctance to involve the entire company in a fire alarm test. As a consequence, detectors and alarms have been found installed and not connected. In one instance, after recalling the installer and

obtaining assurance that the system had been activated, a test again failed to produce an alarm. It was apparent that not only was insufficient information available for the people charged with using the fire alarm system every day but that the installer was also inadequately trained or prepared for assuring delivery of a reliable system.

Although specific fire alarm systems have been found which operated reliably, most systems have problems in design, operation, and maintainability which seriously compromise their overall reliability. The operating assumption appears that the initial designer-installer is the only necessary source of information about the system and that it is capable of functioning without maintenance for an indefinite period of time at a near perfect level of reliability. The systems examined are subject to regulation and inspection; hence they would have been expected to be of better quality than those found in many industrial and commercial establishments. If this is indeed the case, significant improvements in both man and machine aspects of the system are required for adequate fire alarm operation.

3.3 Fire Detection

Fire detection is the weakest link of the detect-alarm-extinguish chain. Numerous reasons for this exist. First, historical real fire experience on detector performance is poorly documented, a fact often due to poor identification of the detection system employed in terms of type, sensitivity setting, adequacy of area coverage. etc. This is compounded by the fact that, until recently, the majority of nonthermal (slow response) detectors were of dubious quality and often incorrectly installed and improperly introduced into the detect-alarm-extinguish chain.

In addition, while suppression agents and techniques usually lend themselves to laboratory quantification, with admitted adjustments for scale, detectors and detection systems are difficult to fully evaluate since there is not a straightforward

description of the required performance. Also, fire detectors are caught in a tradeoff between success in detecting fires and false alarms. Thus, a more sensitive detector may not be a better detector in the end use.

This difficulty extends even to the design of full-scale fire experiments to evaluate specific detector installations - what fire scenario to duplicate. Obviously, the problem is compounded when attempting to determine a proper "standard test" by which to generally rank detector performance. It is evident that the nuclear insurance and regulatory agencies are aware of these problems by the lack of depth of fire detection treatment in the various guides. Specific generic suppression systems (or a select few) are recommended for specified areas of nuclear power plants and codes and standards are identified pertinent to their selection, design, and installation. In contrast, detection is identified as necessary and standards are listed; however, no selection guidance is provided related to area of use. The standards and test procedures also offer little quantitative information for selection between generic types and generally are limited to offering means of relative ranking within each class by differing test procedures not intercorrelated.

3.3.1 Heat Detectors

Until recent years, most fire detectors were "heat" detectors. These react upon achievement of a selected sensor temperature (fixed temperature detectors) or a rate of change in temperature (rate of temperature rise detectors) due to heating. Fixed temperature detectors employ eutectic metals which melt to open a circuit or release a spring, or use a variety of temperature sensing techniques such as:

- bimetallic strips (bend or "snap")
- thermocouples or thermistors (voltage)
- expanding liquids or gases (pressure)
- synthetic fibers (melt or stretch)

Certain of these techniques return to their original condition (self-restoring) upon cooling. Others are "one shot" devices that must be replaced after actuation.

While often thought of as "spot" detectors (monitor conditions at one point in space), heat detectors are also available as "line" detectors. As their name implies, line detectors can monitor an increase in temperature anywhere along their length. Common line detectors are:

- pneumatic (tubing filled with liquid or gas),
- capacitance (heat caused, reversible change in insulation between parallel conductors), and
- "twin wire" (separated by a low melting plastic).

Rate of rise detectors also employ various sensing techniques. One method is to contain gas in a closed chamber with a prescribed leak. Rapid heating causes a pressure rise since gas expansion rate exceeds the design leak rate. Differential expansion of two similar elements due to unequal heating rates caused by configuration or insulation also can indicate an excessive "rate of rise" by closing a set of contacts.

Rate compensation detectors are designed to actuate at a prescribed temperature, or, sooner if the upward rate of rise is rapid. This also can be achieved by differential expansion of two elements, where the elements are of materials with different coefficients of expansion. Heated very slowly so that temperature rise is quite uniform on both elements, contact closure at the desired temperature occurs due to the differences in expansion coefficients. Insulation or the configuration allows more rapid heating of the element having the highest expansion coefficient causing contact closure at a lower net temperature of the hot gases.

The role of heat detectors in the protection system for anechoic chambers is best limited to suppression actuation. They do not perform well as early warning devices for this application.

3.3.2 Smoke Detectors

Attention to residential fire safety has created an astounding upsurge in the sales of smoke detectors. The term "smoke detector" is applied to all detectors sensing the presence of fine particles (smoke) in the air to indicate the presence of fire. The oldest of these, the projected beam detector, was not among the units caught in this upsurge, primarily due to constraints of cost, installation and maintenance.

3.3.2.1 Projected Beam Detectors

The projected beam detector senses smoke as a reduction in signal from a photoelectric cell caused by smoke obscuring light (a collimated beam) from reaching the photocell (see Figure 11). This obscuration is a combination of absorption and scattering. While not a popular residential smoke detector, the projected beam smoke detector has commercial/industrial use, and serves as a reference tool in smoke detector testing and various aspects of fire research.

Projected beam detectors are available that employ visible, IR or UV "light beams". They offer the advantage of "line" rather than "spot" detection. This is of particular advantage to anechoic chamber use, since a lesser number of detectors are required (than spot detectors) within the chamber for a given "area of coverage". Of greater importance is the fact that light source and photocell can be nestled in the base juncture of adjacent cones, offering less chamber disturbance than spot detectors whose sensing hardware must be accessible to the smoke "flow". In addition to an alarm signal, a proportional signal from the photocell may be readily monitored to assist in determining maintenance schedules to reduce false alarms due to service related causes (dirt on lenses, photocell aging, etc.).

3.3.2.2 Ionization Detectors

A major portion of the residential market has been captured by "ionization detectors". These employ a radioactive source to ionize air between two electrodes causing a small current to flow.

The presence of aerosols or smoke particulates in the chamber reduces ion mobility thus reducing current flow (see Figure 12). Most detectors employ radioactive sources releasing alpha particles to ionize the air; however, one unit uses a beta source. Ionization detectors respond best to the "invisible" combustion particles having nominal diameters in the 0.01 to 1 micrometer range.

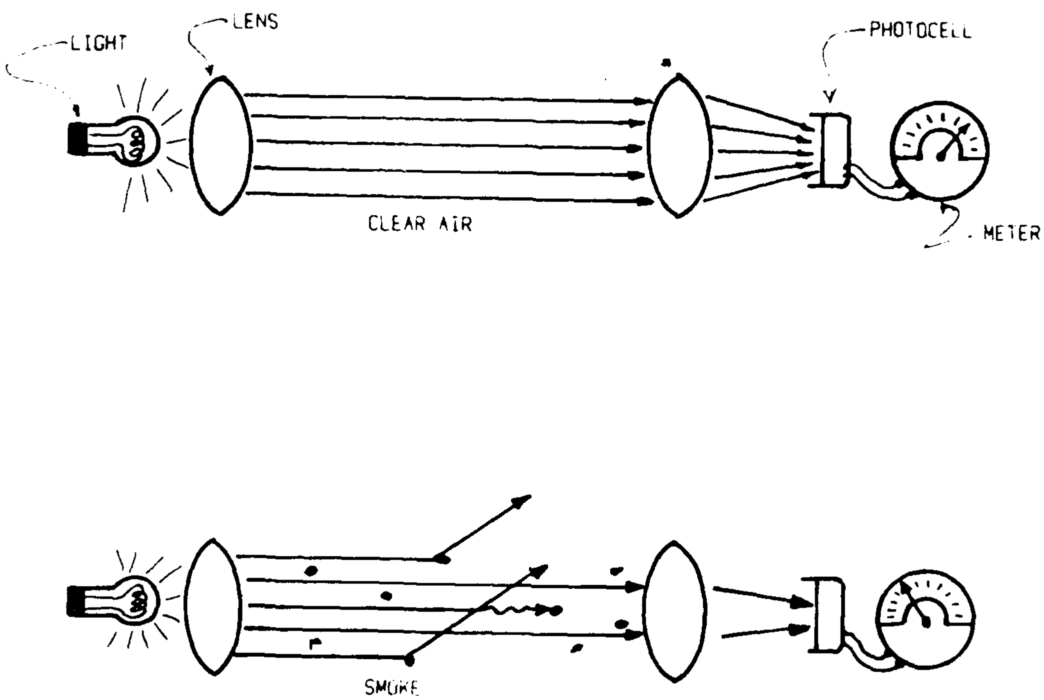

FIGURE 11. Projected Beam Photoelectric Smoke Detector.

Ionization detectors are "spot" detectors and must be accessible to the "smoke flow" in the chamber. This presents an interface problem. Their use in return air ducts offers limited benefit since smoke laden air is significantly diluted at this position. These and other "spot" detectors may offer advantages as part of a remote sampling system to be discussed later.

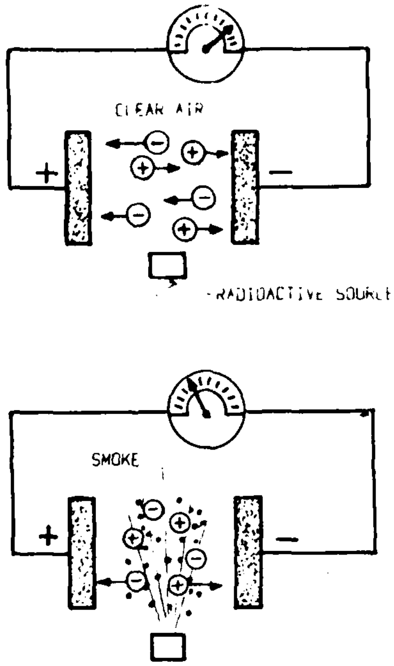

FIGURE 12. Ionization Smoke Detector.

Another problem exists in that ionization detectors may respond to electromagnetic radiation in the chamber. This problem has been solved, in other applications, by shielding the detector with a "top hat" of perforated foil, with some associated degradation in response time.

The other popular smoke detector for residential use is called the "photoelectric detector". It differs from the projected beam smoke detector, which also employs a photocell, in that it measures the ability of smoke to scatter a collimated light team. Early models generally placed the photocell at approximately right angles to a projected light beam in a small enclosure. These are called "side scattering photoelectrics" (see Figure 13). The enclosure entries formed a labyrinth to preclude stray outside light from influencing the photocell while permitting smoke to enter. More recently, a configuration

has evolved where the photocell is nearly in the path of the light beam, protected from line of sight by an intervening wall. This wall prevents any scatter due to deposits in the lens of the light from reaching the photocell. Light scattered at a slight angle by smoke just above this wall reaches the photocell causing a signal. This is the "forward-scattering photoelectric" (see Figure 14). Response characteristics of the forward-scattering photoelectric detector are less sensitive to particle size providing more uniform response to a variety of smoke sources.

An important advance in photoelectric detectors was the substitution of pulsed light-emitting diodes (LEDs) for incandescent light bulbs as the light source. Two obvious advantages were gained. First, by revising the electronics to monitor the magnitude of the pulse rather than total signal generated, stray light can be tolerated and the sensing chamber no longer requires elaborate labyrinths. This reduces the "time lag" for smoke outside the detector to pass into the sensing area. A second benefit is that the pulsed LED and the supporting electronics require very little power making battery operation practical.

3.3.3 Flame Detectors

Flame detectors can be designed to sense ultraviolet (UV), visible, or infrared (IR) radiation from flames or glowing embers. Flame detectors provide the fastest detection time of any detector to these stimuli, but are insensitive to smoldering fires where surface glow is not present.

Flame detectors also have the highest false alarm rate of any detector in general applications. This limits their use to special high hazard areas where their fast response is a necessity (hypobaric chambers, industrial processes, etc.). In these cases, their false alarm propensity is tolerated, and steps are taken to minimize false stimuli within their field of view. Where false stimuli cannot be eliminated, flame flicker detectors are sometimes used to discriminate between the "flicker" of natural fires and the more constant level of certain false stimuli (sunlight, etc.).

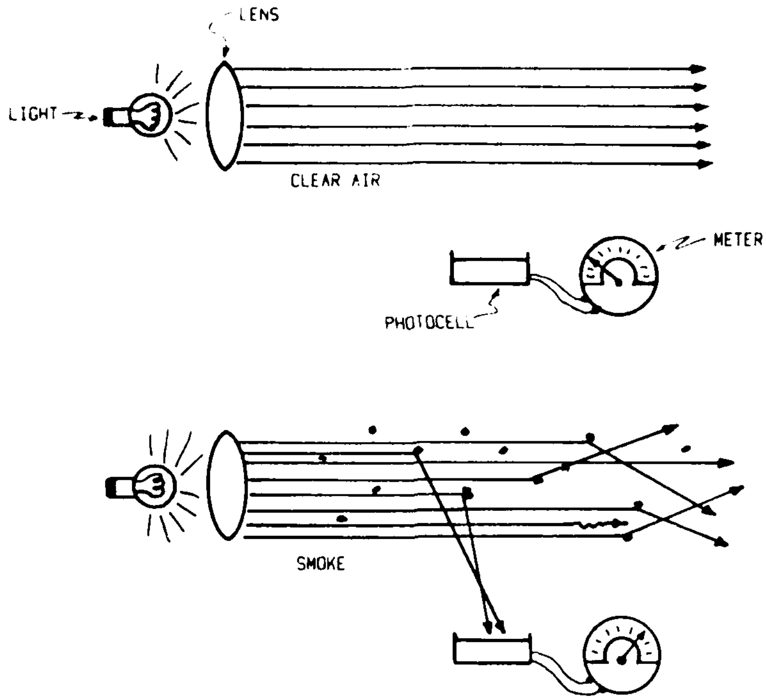

FIGURE 13. Side-Scattering Photoelectric Smoke Detector.

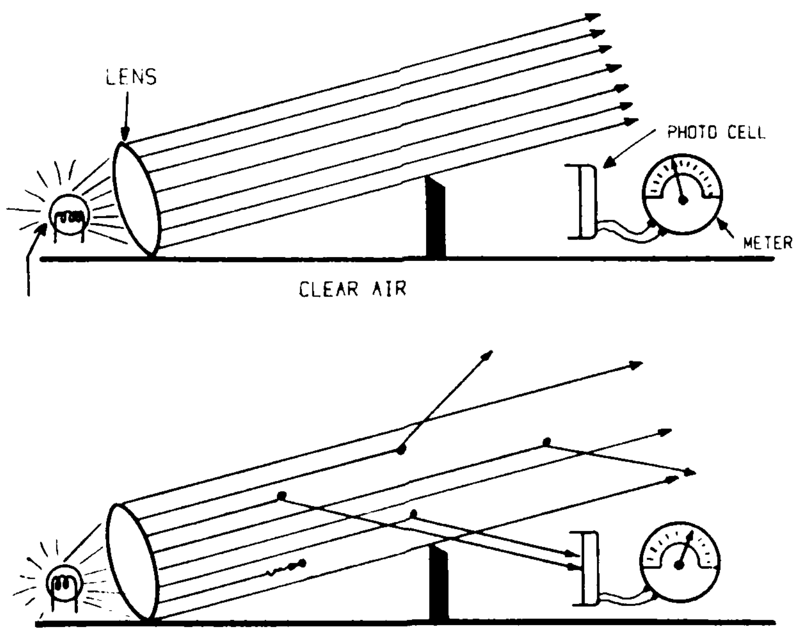

FIGURE 14. Forward-Scattering Photoelectric Smoke Detector.

Flame detectors are line-of-sight devices; and must "see" the fire. Their cones of view typically range from 15 to 170 degrees. The devices are operated in fixed position or may be controlled to scan a larger area (a scanning narrow angle, high sensitivity sensor provides advantage over a wide angle sensor monitoring the same total view).

3.3.3.1 IR Detectors

IR detectors are sensitive to solar radiation which should not be a problem inside an anechoic chamber. Should certain man-made false stimuli be a problem, this can be overcome by selecting a narrow band of IR energy for operation (filtering). Flame flicker techniques can also be employed.

3.3.3.2 UV Detectors

These are insensitive to both sunlight and artificial light, operating in the range of 0.17 to 0.30 micrometer. Generally, viewing angles range from 90 to 170 degrees. In some models, self-checking of sensitivity loss (due to dirt on the viewing lens, faulty sensor or failing electronics) is achieved. A self-contained UV source emits a signal through the lens edge to a mirror where it is reflected back through the lens to the sensor. This action is sequential with normal monitoring.

3.3.4 Remote Sampling Systems

These systems employ a centralized smoke sampling device which sequentially examines samples of the atmosphere drawn from various protected locations through small plastic (or metal) tubes. They have the advantages of multiple spot detectors without requiring that hardware sets be placed at each monitoring location, a particular advantage to anechoic chamber fire protection.

Transport of samples through tubing may cause particle deposition, particularly of larger particles. For this reason, detectors employed in such systems tend to be those most sensitive to smaller particles. In fact, advantage has been taken

of this, and the atmospheric sample is often preconditioned to remove all but very small particles prior to being passed through the sensing chamber, by this means reducing false alarms.

Sensors employed in remote sampling systems have generally been of the following types:

- Condensation Nuclei Type - the atmospheric sample is first humidified to 100 percent, and then passed into a chamber where pressure can be suddenly reduced. Particles in the humidified sample act as nuclei for the condensation of water on a one droplet per particle basis. These droplets are large enough to permit photoelectric (light scattering type) detection.
- Quartz Crystal Type - by passing the atmospheric sample through an impact separator, all but the smaller particles (<0.7 micron) are removed. These are then directed through a nozzle to impact on the face of a quartz crystal (50 percent of 0.3 to 0.7 micron particles are deposited). The added mass on the crystal changes its resonant frequency, the monitored quantity.
- Modified Ion Chamber - developed for use in the space shuttle, as was the quartz crystal type, this device employs the same impact separator used above, but substitutes an ionization chamber as the sensor. The particular sensor used is designed for high sensitivity to the very small particles.

3.3.5 Performance Overview

As intimated earlier, specific fire detection techniques lend themselves to specific fire protection problems. The challenge is to select the technique or combination of techniques best suited. The obvious guides for selection are sensitivity and, to be practical, cost. Certain detectors are found to be more sensitive to particular fire signatures than others. If the expected fire signature can be defined with confidence, a preferential detection technique can be more readily defined. Other factors play an important role. These were described by Grabowski (Ref. 27) and presented in earlier discussions. They are repeated here in abbreviated form for reference.

<u>Sensitivity</u> - the response of the device or system to defined fire signatures, generally inherent in the design.

<u>Reliability</u> - often confused with the above, reliability is a measure of the ability of the device or system and each component to perform its intended function at any given time.

<u>Maintainability</u> - the need to clean, adjust, service, etc., to assure reliability during the intended working life of the device. The term high maintainability means little or no maintenance is required.

<u>Stability</u> - the ability to retain original sensitivity over time, neither increasing or decreasing.

Grabowski suggests the summary shown in Table 12 to be indicative of performance of devices or systems available in 1972. Perhaps the recent advances in photoelectric detectors should now rate them as high in sensitivity rather than medium.

TABLE 12. Detector Equipment Performance Summary (Ref. 27).

Detector	Sensitivity	Reliability	Maintainability	Stability
Fixed temperature	Low	High	High	High
Rate of rise	Medium	Medium	High	High
Rate compensated	Medium	High	High	High
Ionization	High	Medium	Medium	Medium
Photoelectric	Medium	Medium	Medium	Medium
Flame-UV	High	Medium	Medium	Medium
Flame-IR	Medium	Medium	Medium	Low

It should be pointed out that the description categorizations presented above are somewhat interrelated for certain detectors. For example, many smoke detectors are capable of much higher sensitivity than that set by the manufacturer. One reason for the manufacturer selected sensitivity setting is that an increased sensitivity setting means increased false alarms. The false alarm increase may be due to the presence of contaminants in the area to be protected with signatures to which the

particular sensor also responds. However, it well may be that stability is the problem thus requiring a sensitivity setting sufficiently low to preclude inadvertent shift into the "false alarm" region.

The "false alarm" is a constraint on sensitivity of all detectors. If it were not for "false alarm" problems, heat detectors would be set for 76°F in areas heated to 75°F; and photoelectric detectors would sense the presence of one particle in the light beam.

Various techniques are used to modify detector (or system) sensitivity and false alarm rejection. The most common means of rejecting false alarms is to require more than one detector or more than one type of detector to signal before certain actions are taken. Most recently, combined photoelectric-ionization detectors have been marketed for residential applications in order to take advantage of the photoelectric's response to smoldering fires and the ionization's response to flaming fires in a single station detector.

3.3.6 Summary of Fire Detection Devices

Appendix E presents a tabular summary description of most common fire detection devices as well as other devices where performance as fire detectors is questioned. Included are devices or systems which are under development. A description of each device is given, and common applications and unique characteristics of each are noted. References are cited identifying sources of further information, and are listed immediately following the tabular material.

3.4 Fire Suppression

Haessler (Ref. 35) states the primary methods of fire extinguishment as:

- removal of fuel
- reduction of heat
- reduction of air
- inhibition of flame chain reactions

These might be restated, more descriptively, as:

- isolation of the reactants from the combustion zone
- intensive cooling of the reactants and the combustion zone
- dilution of the reactants by a nonreactive material
- chemical retardation of the combustion reaction

Cooling the fuel is most practical for combustibles that do not generate flammable vapors at ambient temperatures. This applies to solid combustibles and to high flash point liquids. Liquids with flash points below normal ambient temperature cannot usually be effectively extinguished by cooling. Water is the most common coolant used for extinguishment.

Separating fuel from the oxidant, normally air, prevents continuation of the reaction. This separation must be maintained until the material has cooled below its ignition temperature and no ignition sources are left to reignite the material. Foam and light water on Class B fires, and multipurpose dry chemicals on Class A fires act in this manner.*

The combustion process actually consists of a repeating sequences of reactions involving free radicals particularly, OH, O, and hydrocarbon radicals. These reactions must continue for the fire to be self-sustaining. Certain chemicals such as metallic salts and hydrocarbon halides inhibit these reactions and thereby extinguish a flame.

The agents most commonly used for fire suppression include water, protein foams, fluorochemical surfactants, dry chemicals, CO_2, and hydrogen halides.

* Class A fires - fires in ordinary solid combustibles; Class B fires - burning liquids and gases; Class C fires - fires in proximity of, or involving electrical equipment.

The fire suppression agent is the basic resource required to negate a fire threat. The equipment and manning required to deliver an agent are all interrelated. In general, it can be considered that the characteristics of the agent will dictate the equipment and the equipment will dictate any manning. The principal dependent variables of fire suppression are:

- fire control* and/or extinguishing* time
- quantity of agent required for control
- quantity of agent required for extinguishment
- permanence of suppression

Fire control time is defined as the time at which the fire is sufficiently reduced in intensity so that it does not present an immediate direct hazard to occupants or facilities.

Fire suppression may be accomplished by local application of agent directly on the (base of the) fire. This technique is most often employed with liquid or solid agents. Gaseous agents may be applied locally, but also permit "total flooding" of confined spaces in order to attack the fire wherever it may be within the space.

The significant functional parameters of locally applied fire suppression are the fire extinguishing agent and the agent application rate. These parameters, when related to the variable of fire configuration, can define fire control time, agent required to control and total agent required to extinguish.

The typical relation between fire control and extinguishment time and agent application rate is presented in Figure 15. At low application rates the time required increases rapidly and approaches infinity below a limiting or critical application rate. This is the minimum rate at which the fire can be suppressed. Increasing the application rate above the critical

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* Fire "suppression" implies fire "control". That is, the fire may not be "out" (extinguished), but it no longer poses an immediate threat.

value decreases the fire control time although at higher application rates increasing the rate only results in a small decrease in time. The total agent requirements as a function of application rate are typically related as indicated in Figure 16. The point below which the agent requirements approach infinity corresponds to the critical application rate. The minimum agent requirements occur at a rate slightly above the critical rate. Increasing application rate above the minimum rate results in a gradual increase in total agent requirements.

The significant functional parameters of total flooding fire suppression are agent concentration in the confined space (rate of delivery of agent influences fire size by affecting the time at which maximum agent concentration is achieved) and "soak time" or duration of the retention of the desired agent concentration. Obviously, short "soak times" may not permit sufficient cooling so that the fire may rekindle once fresh air is readmitted. Another problem, the deep seated fire, also impacts the soak time required.

The occurrence of deep seated fires is peculiar to certain solid fuels. Liquids and many solid fuels burn by first vaporizing the constituents and then reacting with oxygen in the vapor phase above the fuel. Some solids burn without vaporization (e.g., glowing charcoal), a solid-gas reaction occurring on the solid surface. Agents which suppress fire by inhibiting the flame chain reaction attack the vapor phase reaction, but not the solid-gas reaction.

Where the solid-gas reaction occurs on an exposed surface, suppression of vapor phase reaction may permit natural cooling to bring surface combustion to a halt since that solid-gas reaction produces less heat. However, in the case of a porous solid or other configuration where heat is somewhat confined, the solid-gas reaction may provide sufficient heat to sustain combustion for long periods, and a "deep seated" fire is the result. There is no line of demarcation between the two types of fires. NFPA standards arbitrarily and somewhat circularly define a surface fire as one that can be completely extinguished by 5 percent Halon 1301 within a soaking time of 10 minutes.

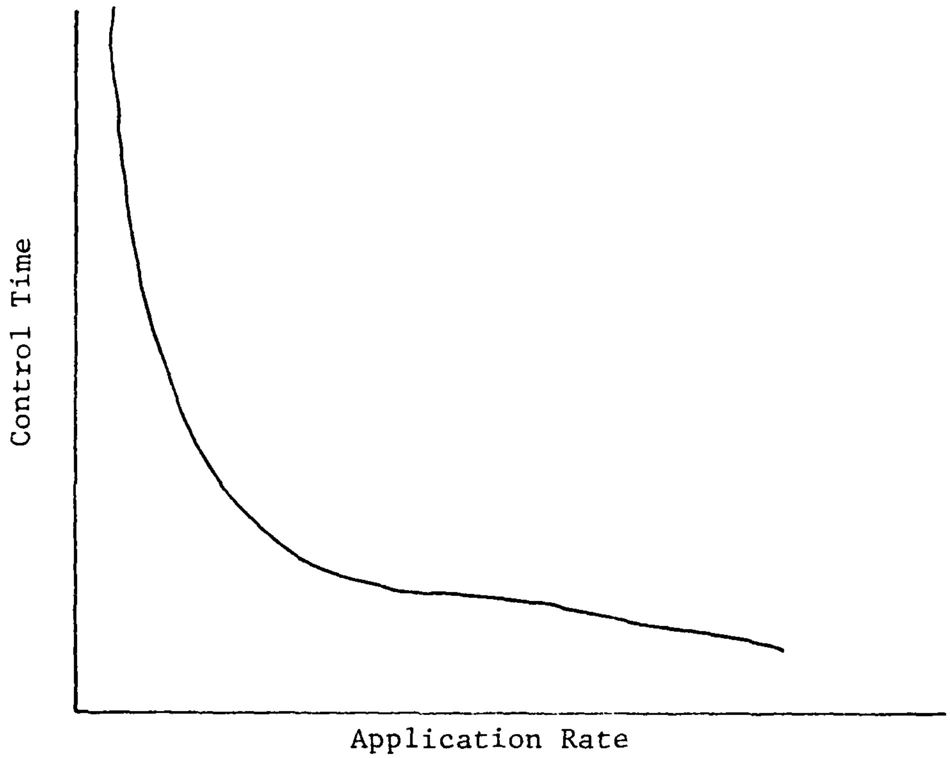

FIGURE 15. Typical Control Time Application Rate Relation.

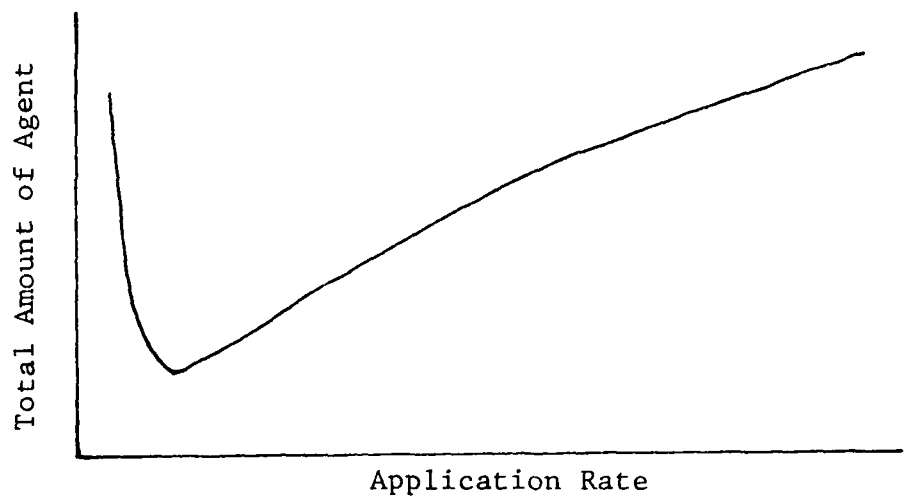

FIGURE 16. Typical Agent Application Rate Relation.

3.4.1 Design Basis Fires

Although some tests have been made to demonstrate that plastics do not produce deep seated fires, these results are not considered valid. Foam polymers when heated have been known to continue heating spontaneously to ignition; such a resulting fire would definitely be deep seated. In an anechoic chamber similar heating could occur as a result of a high resistance electrical fault through the carbon impregnated foam to ground. Glowing combustion of polymers, a characteristic of a deep seated fire, has also been observed in cable insulation fire tests at Sandia Laboratories. Therefore, we believe it is necessary to assume that a deep seated fire in the polymer foam is possible and the protection must be designed accordingly.

Polymeric foams installed inside structures have fueled numerous rapidly spreading fires which have overpowered ordinary automatic sprinkler systems. The report of the May 1979 fire in an anechoic chamber at Hughes Aircraft indicates that such a fire is possible with non-fire retardant anechoic foam. Factory Mutual tests show that such fire development is also possible in fire retardant foam installations.

Users and suppliers of the fire retardant foams state that they cannot be ignited by ignition sources such as a cutting torch. However, this is not always a reliable index. An important factor to consider is the relation between thermal flux applied to a combustible and the heat release rate from the combustible. The higher the thermal flux applied the higher the rate of heat release from the combustible. The more intense an igniting fire the more intense will be the initial fire. The more intense the initial fire the higher flux rate it will transmit to uninvolved combustibles and consequently the faster the fire will spread. With cellulose materials, heat release rate is approximately a linear function of the applied thermal flux. However, with polymeric materials, the linear approximation generally exists up to a particular level of applied thermal flux; beyond this level there can be a rapid increase in the

heat release rate with further increases in applied thermal flux. This phenomenon has been the cause of the major discrepancy noted between some fire test evaluations of polymers and their experience with actual fires.

The Factory Mutual corner tests show that with a high intensity ignition source a rapidly developing fire is possible even with fire-retardant anechoic foam. If their crib represents a reasonable equivalent of a fire that might expose chamber walls and ceiling, a rapidly developing fire will be possible in the anechoic chamber.

3.4.2 Fire Suppression Agents

Table 13 presents a summary of fire suppression agents. Agents are categorized by their physical state at time of application (solid, liquid, gas) and identified by chemical composition. Their applicability to solid or liquid fuels and electrical fires is indicated under Fire Classification. Primary extinguishment mechanisms are also given along with general comments addressing advantages, disadvantages, and use requirements. Selected pertinent references* identify additional source material. In the paragraphs to follow, additional descriptions are provided for the agents deemed most appropriate to use in anechoic chambers.

3.4.2.1 Water

The oldest and most basic of all fire extinguishing agents is water. It can be used to suppress any kind of fire, with the exception of highly reactive metals such as sodium. The principal advantages of water are its high latent and specific heats, its low cost, the ease with which it can be transferred and applied, and in general, its local availability. Its high freezing temperature and poor blanketing characteristics are two disadvantages.

Additives are often used with water to improve its advantages or negate its disadvantages. Wetting agents added to water decrease its viscosity and increase the rate at which the water

* These references appear immediately following the table.

TABLE 13. Fire Suppression Agents.

Agent	Composition	Fire Classification	Extinguishing Mechanism	Comments	Ref.
GASES					
Nitrogen, Argon, etc.	Industrially pure gases	- Satisfactory on Class B fires - Satisfactory on Class C fires	Blankets fuel (reduces oxygen)	Seldom used	2 1 4-Sec 13 7 6-Chap 1 5-Chap 14 Chap 15
Carbon Dioxide	Industrially pure CO_2	- Satisfactory on Class B fires - Satisfactory on Class C fires - Limited use on Class A fires	Cools and blankets fuel	- Does not react with most substances - Only mildly toxic; however, 9% conc. is threshold limit of anoxia - Can be applied locally to blow out flame or used in total flooding at 30-75% conc. - Stored as both liquid and gas; high pressure storage, 850 psi, requires heavy cylinders; low pressure, 300 psi requires refrigeration to $0^{\circ}F$ - Possible cold shock to sensitive electronic parts - No residue	23-p14-16 24-p36-37 25-p13-14 26-Table 7-1
HALOGENATED HYDROCARBONS:					
Bromotri-fluoromethane (Halon 1301)	CF_3Br	- Satisfactory on some Class A fires - Satisfactory on Class B fires - Satisfactory on Class C fires	Inhibits flame reactions	- Can be used locally or in total flooding system - Least toxic halon; normal extinguishing concentrations (7%) present no immediate problems, higher concentration may cause health problems, especially after decom-position - Second most effective Halon - Most commonly used Halon today - Low extinguishing concentrations required (3-20%) - Slight decomposition products (not particularly corrosive)	

TABLE 13. (Contd.)

Bromodifluoro methane (Halon 1211)	$CBrClF_2$	- Satisfactory on Class B fires - Satisfactory on Class C fires	Inhibits flame reactions	- Too toxic for total flooding in occupied area - Common in local applications - Low extinguishing concentrations required (3-20%) - Slight decomposition products (not particularly corrosive)	
LIQUIDS (aqueous)					
Water (solid stream)	H_2O	- Satisfactory on Class A fires - Limited use on Class B fires where flash point is 150°F	Cools fuel	- Oldest and most widely used agent - High latent and specific heats - High availability - Some problems with high freezing points - Poor blanketing characteristics - Problems with electrical conductivity - Solid streams make long range accessibility - Possible equipment damage due to presence of water	4-Sec 13 7 6-Chap 1 5-Chap 10 23-p18 24-p34 25-p14 26-Table 7-1
Water (spray or fog)	H_2O	- Satisfactory on Class B fires - Satisfactory on Class C fires - Limited use on Class D fires	Cools and blankets fuel	- General properties of water plus blanketing characteristics	
Water and detergent (wetting agent)	H_2O and synthetic detergents	- Satisfactory on Class A fires - Limited use on Class B fires	Covers or coats, and cools fuel	- Lowers surface tension of water - Foam deposits, delay water run-off, increases cooling effect - Film form tendency precludes its use against electrical hazards - Low on toxicity	23-p18 24-p43 15

TABLE 13. (Contd.)

Water and thickening agents	H_2O and viscosity agents such as: "CMC" (Sodium Carboxymethycel-lulose) "Gelgard", Gums Bentonite clays	- Satisfactory on Class A fires - Effective on fires where radiation is at an advantage, e.g., forest fires	Covers or coats, and cools fuel	- General properties of water and increased coating characteristics and resistance to drift	4-Sec 13 Chap 1 23-p20
Water Slurry	H_2O and a mixture of sodium and calcium borates	- Satisfactory on Class A fires only	Covers or coats, and cools fuel	- Similar to water and thickening agents, but after water is evap-orated, borate crystals lose their water of hydration, after which they form a glassy coating	4-Sec 13 Chap 1 6-Chap 1 25-p20
Water and alkaline salt	H_2O and alkaline salts, such as Potassium Carbonate	- Satisfactory on Class A fires only	Covers or coats, and cools fuel	- Salt solution weakens char particles which break off and are extinguished leaving underlying material wetted down, which when evaporated, leave a crystalline somewhat fire retardant barrier - "Loaded system" - Can be rendered non-freezing to -40°F	4-Sec 13 Chap 1 23-p20
Chemical foams	H_2O and aluminum sulfate "A" and sodium bicar-bonate "B"	- Satisfactory on Class A fires - Satisfactory on non-water soluble Class B fires	Covers or coats fuel	- No longer used due to economics and ease of handling of liquid foam concentrates - High salt content makes it a high conductor of electricity	4-Sec 13 Chap 1 6-Chap 1 23-p20
Protein foams	H_2O and protein base stabilizers made from slaugh-ter house products	- Satisfactory on Class A fires - Satisfactory on non-water soluble Class B fires	Covers or coats fuel	- A type of "air" or "mechanical" foam - Greater fire resistance than detergent base foam - Cannot be pre-mixed with water for an indefinite length of time - Applied in 3-6% solution; 7-12 x expansion	5-Chap 1? Chap 13 6-Chap 1 23-p20 24-p40
Fluoroprotein foams	H_2O and protein base stabilizers, plus a fluorinated surfactant	- Satisfactory on Class A fires - Designed for use on Class B fires	Covers or coats fuel	- Fluorinated surfactants give a fuel shedding property to the foam ex-cellent for use in Class B tank fires - Applied in 3-6% solution; 7-12 x expansion - Non-toxic, biodegradable	5-Chap 13 6-Chap 1 16-p30 23-p20

TABLE 13. (Contd.)

Synthetic detergent based foams	H_2O and a blend of aryl and alkyl sulfonates	- Satisfactory on Class A fires - Satisfactory on non-water soluble Class B fires		- Applied in 3-6% solution; 12-20 x expansion - Does permit pre-mixing for extended periods of time	4-Sec 13 7 5-Chap 13 6-Chap 1
Insoluble protein and detergent foams	soluble metallic salts, and insoluble soaps added to prevent soluble up through foam	- Satisfactory on Class A fires - Satisfactory water-soluble Class B fires	Covers or coats fuel	- Applied in 3-6% solution, 7-12 x expansion - Effectiveness is limited by a short time factor (½-1 min) - Possible water damage	23-p23 4-Sec 13 7 5-Chap 13 6-Chap 1
High expansion foams	Synthetic detergent foam with very low density assemblage of bubbles	- Satisfactory on Class A fires - Satisfactory on Class B fires - Limited use on Class C fires	Covers or coats fuel	- Applied in 2% or greater concentrations - 100-1000 x expansion - Suited for use as flooding agent in enclosed and inaccessable areas - Slight clean-up problem - Extinguishing action is relatively slow - Provides protection from reignition	4-Sec 13 7 5-Chap 13 6-Chap 1 24 p40 26-Table 7-1
Combined foam and dry chemicals	A variety of foams are compatible with a variety of dry chemicals, but there are many incompatible cases	- Satisfactory on Class A fires - Satisfactory on Class B fires	Covers or coats fuel	- Dry chemical additives act as absorbants, thus lowering the evaporation rate of liquid fuels - Suitable for spill fires - Clean-up problem - Care must be taken in selection of compatible agents - Foam and dry chemicals are applied through separate means	16-p30 6-p83 23-p23
<u>LIQUIDS</u> (non-aqueous)					
HALOGENATED HYDROCARBONS:					
Chlorobromomethane (Halon 1011)	CH_2BrCl	- Satisfactory on Class B fires - Satisfactory on Class C fires - Limited use of Class A fires	Inhibits flame chain reactions		4-Sec 13 7 6-Chap 1 21 5-Chap 15

TABLE 13. (Contd.)

Dibrometetra-fluoromethane (Halon 2402)	$C_2Br_2F_4$	- Satisfactory on Class B fires - Satisfactory on Class C fires - Limited use on Class A fires	Inhibits flame chain reactions	- Not used in U.S. - Limited applications in aircraft systems and extinguishers	23-p16 25-p14
Dibromodi-fluoromethane (Halon 1202)	CF_2Br_2	- Satisfactory on Class B fires - Satisfactory on Class C fires - Limited use on Class A fires	Inhibits flame chain reactions	- Most effective halon - Used by USAF in aircraft systems	
Methyl Bromide (Halon 1001)	CH_3Br	- Satisfactory on Class B fires - Satisfactory on Class C fires - Limited use on Class A fires	Inhibits flame chain reactions	- Problems with toxicity	
Carbon Tetra-chloride (Halon 104)	CCl_4	- Satisfactory on Class B fires - Satisfactory on Class C fires - Limited use on Class A fires	Inhibits flame chain reactions	- Popular in past until its toxicological problems were defined	
Methyl Iodide (Halon 10001)	CH_3I	- Satisfactory on Class B fires - Satisfactory on Class C fires - Limited use on Class A fires	Inhibits flame chain reactions		
Bromochloro-fluoromethane (Halon 1211)	$CClBrF_2$	- Satisfactory on Class B fires - Satisfactory on Class C fires - Limited use on Class A fires	Inhibits flame chain reactions	- In common use for local application - Also, used as a gaseous agent **Concerning all Halons:** - No criticality hazard - Low contamination spread hazard - Slight decomposition products (non-corrosive)	
Halon Foam	A mixture of halons and compatible surfactants	- Satisfactory on Class B fires - Satisfactory on Class C fires - Limited use on Class A fires	Covers or coats fuel, and inhibits flame chain reactions	- Developed for Air Force	3 23-p32

TABLE 13. (Contd.)

Synthetic Fluids	Cyclic boron compounds: -trimethoxyboroxine -tri-cresyl phosphate -dioctyl phthalate	- Satisfactory on Class A fires - Satisfactory on Class C fires - Satisfactory on Class D fires	Covers or coats fuel	- Developed for metal fires, e.g. molten sodium in atomic reactors; metal alloys in rocket fuels - Very toxic	6-Chap 1 23-p23
SOLIDS					
Sodium Bicarbonate Base Powder (Alkali)	$NaHCO_3$	- Satisfactory on Class B fires - Satisfactory on Class C fires	Cools fuel, inhibits flame chain reactions, and shields radiation	- Dry chemical powders rangr from 75-100 microns in diameter - Clean-up problem - "Standard" dry chemical - Very popular - Least expensive - Non-toxic - Non-conductive	4-Sec 13 Chap 5 7 6-Chap 1 5-Chap 6 6-Chap 1 18-p51 23-p25 24-p39
Potassium Bicarbonate Base Powder (Alkali)	$KHCO_3$	- Satisfactory on Class B fires - Satisfactory on Class C fires	Cools fuel, inhibits flame chain reactions, and shields radiation	- "Extra effective" dry chemical - "Purple K" - None-conductive - Clean-up problem	25-p13 26 Table 7-1
Potassium Carbamate Base Powder (Alkali)	NH_2COOK	- Satisfactory on Class B fires - Satisfactory on Class C fires	Cools fuel, inhibits flame chain reactions, and shields radiation	- Twice as effective as most BC powders - Expensive - "Monnex" - Non-conductive - Clean-up problem	
Potassium Chloride (Neutral)	KCL	- Satisfactory on Class B fires - Satisfactory on Class C fires	Cools fuel, inhibits flame chain reactions, and shields radiation	- Clean-up problem - Super K - Corrosive - Non-toxic - Non-conductive	
(Mono) Ammonium Phosphate Base Powder (Acidic)	Ammonium dihydrogen orthophosphate $(NH_4)H_2PO_4$	- Satisfactory on Class A fires - Satisfactory on Class B fires - Satisfactory on Class C fires - Limited use on Class D fires (depending on fuel)	Covers or coats fuel, cools fuel, inhibits flame chain reactions, and shields radiation	- "ABC"; all-purpose dry chemical - Slightly corrosive when wet - Very popular - Non-toxic - Non-conductive - Clean-up problem	

TABLE 13. (Contd.)

Metal Extinguishing Agents	- Met-L-X powders - G-1 powder - Na-X powder - Lith-X powder - Pyromet powder - Ternary Eutectic Chloride powder - Talc powder - Graphite powder - Sand - Cast iron borings - Sodium Chloride - Soda Ash - Lithium Chloride - Zirconium Silicate - Dolomite - etc.	- Satisfactory on Class D fires	Covers or coats fuel	- Limited by gravitational forces in covering only generally horizontal areas (poorly suited for vertical) - Each agent must be carefully chosen for fuel involved - Clean-up problem	4-Sec 13 Chap 6 23-p30 26-Table 7-1
				Concerning all Solid Agents: - Possible damage to electrical components - General clean-up needed after use	
COMBINATION AGENTS WORTHY OF INVESTIGATION					
CO_2 and water fog Halon and water fog Foam and liquid halons				- Joint use of some of these agents could possible reduce the amounts of agent needed to effectively extinguish, due to the combination of separate extinguishing properties	23-p31 24-p45 23-p32

TABLE 13. (Contd.)

REFERENCES FOR TABLE 13

1. "Aircraft Ground Fire Suppression and Recue Systems - Current Technology Review," F. Salzberg, J. Campbell, IITRI Technical Progress Report AGFSRS 70-1.
2. "A Study of Vaporizable Extinguishants," 1960, Dow Chemical Co., D. Engibcws, T. Torkelson.
3. "Advanced Fire Extinguishers for Aircraft Habitable Compartments," S. Atallah, J. Hagopian, A. Kalelkar, Technical Report AFAPL-TR-72-62.
4. NFPA Fire Protection Handbook, 14th Edition.
5. "Fire Protection for the Design Professional," R. Jensen.
6. "Fire Suppression and Detection System," J.L. Bryan.
7. "Improved Fire Protection for Stationary Underground Equipment," Part I, Proposal No. IITRI-74-188J.
8. Foam Extinguishing Systems '74, NFPA 11.
9. High Expansion Foam Systems, '70 NFPA 11A.
10. Synthetic Foam and Combined Agent Systems, NFPA 1113.
11. Carbon Dioxide Systems '73, NFPA 12.
12. Halon 1301 Systems '73, NFPA 12 1A.
13. Halon 1211 Systems '73, NFPA 12 B.
14. Dry Chemical Systems '73, NFPA 17.
15. Wetting Agents '72, NFPA 18.
16. "Aircraft Fire Protection and Rescue Procedures," 1st Ed., '70 IFSTA.
17. "Controlling Mine Fires with High-Expansion Foam," '60, Bureau of Mines Report 5632.
18. "Improved Sensors and Fire Control Systems for Mining Equipment," Phase 1, FMP Corp., Dec. 1972.
19. "Aircraft Fire and Rescue Facilities and Extinguishing Agents," Dept. of Transportation, AC No. 150/5210-613, '73.
20. Wetting Agent '72, NFPA 18.
21. Vaporizing Liquid Extinguishing Agents '65, NFPA 182M.
22. Symposium on an Appraisal of Halogenated Fire Extinguishing Agents, April '72, Nat. Academy of Sciences.
23. The Extinguishment of Fire, W. Haessler, NFPA #FSP-40.
24. Guide to Fire Protection in Got Cells, Canyons, and Caves, Atlantic Richfield, ARH-3020 RD1.
25. Hot Cell Fire Protection, DuPont, DP-1242.
26. Glovebox Fire Safety, '67 AEC, TID 24236.

penetrates porous materials. Additives are also used which increase the viscosity of water to decrease the rate at which it runs off surfaces and thereby increase the heat transfer from the surface to the water. Finally, foaming agents or surfactants and air are mixed with water to form blanketing foams.

Application of water in a straight stream permits it to penetrate the flame and reach a burning combustible immediately. This does not directly reduce the flame intensity and often puts an excessive amount of water on a local part of the combustible. In addition, if a straight stream hits a burning liquid it scatters the fuel, often spreading the fire. The straight-stream is most efficient on a fire involving solid combustibles when the flame or draft intensity is so great that small water droplets could neither reach the surface nor significantly reduce the flame intensity.

Spray application of water creates small droplets which increase the total surface area for heat transfer. This increases droplet vaporization in the flame, decreases flame intensity, and also distributes the water over the surface of the combustible. A spray is the most efficient way of applying water except when distance, air velocity, flame intensity, or materials would prevent the water from reaching the base of the fire.

The water droplets must have a size/velocity relationship so that most of the droplets reach the surface of the fire. Droplets below 100 to 150 microns in diameter will be largely dissipated in a fire before reaching the surface.* Most of the droplets over 300 microns will reach the surface of the combustible. High-pressure water sprays, 600 to 800 psig, feature high velocity droplets of small diameter. Penetration of the flame is achieved by the high velocity and the small droplets then rapidly evaporate at the base of the fire.

* In an enclosure, these do cool the space by forming steam. The steam, in turn, impedes the influx of air.

High and low pressure sprays are used in flammable liquid fires where a large water supply is available and where a securing and blanketing agent is not. The use of spray in fire suppression is being supplanted somewhat by agents with blanketing action or quick knockdown characteristics.

3.4.2.2 High Expansion Foam

Most foam extinguishants are applied to occupancies where Class B fires predominate. These blanket the fuel, and while effective against Class A fires, generally offer no particular advantage to anechoic chamber fire protection. A disadvantage appears to be cleanup following application, a more significant problem than that which results from water application alone. High expansion foam is the exception to this generalization and offers some potential as a fire protection agent for anechoic chamber applications.

High expansion foam is a very low density assemblage of bubbles, formed by air and a water-foaming agent solution. It is produced by blowing air through a screen which is wetted by a surface active foaming agent. Expansion rates of 500:1 to 1500:1 are typical.

High expansion foam was initially developed for extinguishing fires in coal mines. It has also been promoted for extinguishing structural fires in confined spaces. Since high expansion foam generating equipment is incapable of ejecting the foam to any distance, in use the foam merely fills the enclosure from the bottom up, typically at rate of 3 to 6 ft/min. These rates are not particularly appropriate to the needs being considered here. First, the chamber contains significant combustibles on the ceiling, the last place to be immersed in foam. Second, particularly for large (tall) chambers, the initial fill rate is not realized after the foam has gained height as the weight of foam already present begins to compress, or even break, bubbles near the base.

Due to its low water content, little water damage is attributed to the use of foam. However, this low water content, and the fact that the expansion gas is air, indicates that high expansion foam may not be effective against deep seated fires.* Although the foam may well subdue active flaming, its presence will hinder discovery and manual extinguishment of areas of deep seated character.

3.4.2.3 Dry Chemicals

Dry chemical is a collective term encompassing a family of salts which are used to extinguish fires. With one exception, these salts do not blanket or cool a combustible; their fire suppression is primarily a chainbreaking action which inhibits the free radical reactions necessary to sustain combustion. The salts are used in an anhydrous form composed of fine particles typically 10 to 75 microns in size. The first dry chemical agent introduced was $NaHCO_3$; other salts used currently include $KHCO_3$ (Purple K), $(NH_4)H_2PO_4$ (multipurpose), and KCl (Super K).

All of these agents are effective in controlling flammable liquid fires. The $(NH_4)H_2PO_4$ is the only one considered suitable for general extinguishment of solid combustible fires. The $(NH_4)H_2PO_4$ extinguishes fires in ordinary combustibles by a blanketing action which leaves a gas-sealing crust over the solid combustible. This crust prevents distillation of combustibles from the solid and prevents oxygen from reaching the combustible. This blanketing crust does not form on liquid combustibles. The other dry chemical agents will knock down a fire in solid combustibles and, if only a surface fire is present, it may stay extinguished. However, if the combustible is heated to its ignition temperature, the fire will quickly rekindle.

* On at least one occasion, a liquid pool fire was sustained under a blanket of high expansion foam. This may be attributed to the particular foam density employed.

A major advantage of dry chemical agents is their ability to rapidly reduce the intensity of a fire, commonly termed knock-down ability. Additional advantages, particularly important in portable extinguishers, are that dry chemicals can be applied from a greater distance and are less dependent on skillful application than some other agents. This is a general qualitative evaluation, and it is not possible to define the exact magnitude of the advantages, except for range.

A major disadvantage is the "mess" remaining after use. This, plus probable poor performance against deep seated fires, suggests it not be considered for anechoic chambers.

3.4.2.4 Carbon Dioxide

One of the oldest fire extinguishing agents for use on flammable liquid fires and fires involving energized electrical equipment is carbon dioxide, CO_2. The fire extinguishing action of CO_2 is principally that of blanketing the fuel and displacing the air, although it does slightly inhibit the free radical chain reaction necessary to sustain combustion. CO_2 does not leave a permanent blanket over the fire and if a residual ignition source remains after application of the CO_2, the fire will restart as soon as the CO_2 is dissipated.

The advantages of CO_2 are: it leaves no residue; it is low in cost; it does not react with most materials; it is a nonconductor of electricity and is self-pressurizing for discharge from its storage tanks. Its disadvantages are that it does not leave a blanket over the fire and it can be readily dispersed. Also, the discharging gas-solid mixture is extremely cool and may cause thermal shock damage to apparatus.

Normally CO_2 is stored in high pressure cylinders or in insulated and refrigerated low pressure tanks. When stored at high pressure, the CO_2 will be part liquid and part gas in the cylinder up to an ambient temperature of 87.8°F. Above this temperature, the stored CO_2 is entirely gas. Cylinder pressure ranges

from 750 to 1100 psi at temperatures of 60 to 88°F. Low pressure storage is practical for amounts of 0.25 to 125 tons. A mechanical refrigeration system maintains liquid CO_2 at about 0°F and a corresponding internal pressure of 300 psi.

When liquid CO_2 is discharged into the atmosphere most of the liquid vaporizes. The heat absorbed during vaporization cools the remaining liquid to -110°F where it solidifies into finely divided solid CO_2, dry ice. These solid CO_2 particles are responsible for the typical white appearance of discharging CO_2.

Turning to a gas, CO_2 mixes with and displaces air and therefore can cause adverse physiological effects on exposed personnel. Increase of the CO_2 concentration in inspired air stimulates respiration. As the concentration is further increased, it acts as a diluent leading to anoxia. Short time exposure to slightly elevated CO_2 concentrations does not produce any irreversible damage. The lethal limit of CO_2 is very high, 658,000 ppm with an anesthesia time of 1 min. (Ref. 36). For short-term 30-min. exposures, the maximum allowable concentration is 5 percent. Under typical fire control conditions, a higher limit of about 10 percent is considered reasonable.

Fires in semiconfined areas required about 6 to 7 lb of CO_2 per lb of airflow to extinguish a severe fire. In confined areas a CO_2 concentration of 29.5 percent by volume is necessary to suppress or prevent ignition of n-heptane (Ref. 36). This corresponds to a concentration by weight of about 65 percent. Much higher concentrations are necessary to extinguish deep seated fires in ordinary combustibles. To extinguish active flaming in bulk cellulose materials located in confined spaces, 0.125 lb/ft^3 of CO_2 is needed (Ref. 37). This corresponds to almost complete displacement of the air. Because of the high concentration required to extinguish fires, CO_2 cannot be used to flood occupied spaces for fire suppression unless sufficient warning is given to permit complete evacuation first.

3.4.2.5 Halogenated Hydrocarbons

These hydrocarbons are a family of vaporizing liquids which can be used as fire extinguishing agents. Carbon tetrachloride (CCl_4) was the first of this family to be used as a fire extinguisher; it was followed much later by methyl bromide (CH_3Br). These two agents are being phased out because of toxicity problems. Many other halogenated hydrocarbons have been investigated for fire extinguishment applications--the agents in current use or being considered are listed in Table 14.

TABLE 14. Common Halogenated Hydrocarbon Fire Extinguishing Agents.

Name	Formula	Halon No.	Mol. Weight
Chlorobromomethane	CH_2BrCl	1011	129.4
Dibromodifluoromethane	CBr_2F_2	1202	209.8
Bromochlorodifluoromethane	$CBrClF_2$	1211	165.4
Dibromotetrafluoromethane	$C_2Br_2F_4$	2402	259.9
Bromotrifluoromethane	$CBrF_3$	1301	148.9

These agents extinguish fires by inhibiting the free radical reactions necessary to sustain combustion. They do not leave a vapor sealing blanket over the fuel nor do they significantly cool a fuel.

Halon 1211 and 1301 are the agents currently in wide use. The principal applications are aircraft flight fire systems, aircraft manual extinguishers, supplementary agents on crash trucks, automotive fire extinguishers, and shipboard engine room fire extinguishers.

Since these agents neither cool nor blanket a fuel, they are most suitable for extinguishing surface fires in enclosed spaces which can be totally flooded. Since the agents are heavier than air, their concentrations will be greatest in the lowest levels of the space. The requirements for extinguishing surface fires with Halon 1301 flooding are presented in Table 15 (Ref. 38).

TABLE 15. Agent Requirements for Surface Fire Extinguishment for Halon 1301 Flooding.

Combustible	Volume %	Weight %	Amount in 100 ft^3 Space lb
Acetone, n-heptane, ethanol	5.0	26.0	20
Propane	5.2	27.0	21
Ethylene	8.2	42.0	32

There are no theoretical relationships or adequate experimental data to compute the concentration of halogenated hydrocarbons needed to extinguish all fires by total flooding. Tests conducted for the Boeing 747 transport (Ref. 39) have shown that incipient cargo fires can be extinguished with the application of 4.84 lb of Halon 1301 per 100 ft^3 of volume (~1.3 percent by volume). However, once deep seated fires are established, the required amount is much higher. Figure 17 illustates requirements found for charcoal, shredded paper, corregated cardboard, and low density compressed fiberboard (Ref. 40).

Toxicity of halogenated hydrocarbon extinguishants must be considered both from their natural vapors and from products produced by thermal decomposition. At high temperatures, these agents breakdown yielding carbonyl halides (phosgene type gases). Toxicity data for the natural and pyrolyzed vapor are presented in Table 16 and the amounts of agent in a 100 ft^3 enclosure at the toxic limits are presented in Table 17 (Ref. 41). For further detail, the reader is directed to the comprehensive review by Musick and Williams (Ref. 42).

In extinguishment of fires in ventilated areas, no hazard would be anticipated. The toxic products are quite noxious and the natural tendency is for one to move away. Even CCl_4 and CH_3Br, which are more toxic than Halons, did not create a real hazard in actual fire extinguishment. Almost all injuries and fatalities from those agents were from exposure to the natural vapor--often because of misuse. The 800°C pyrolysis data presented represent an extreme situation.

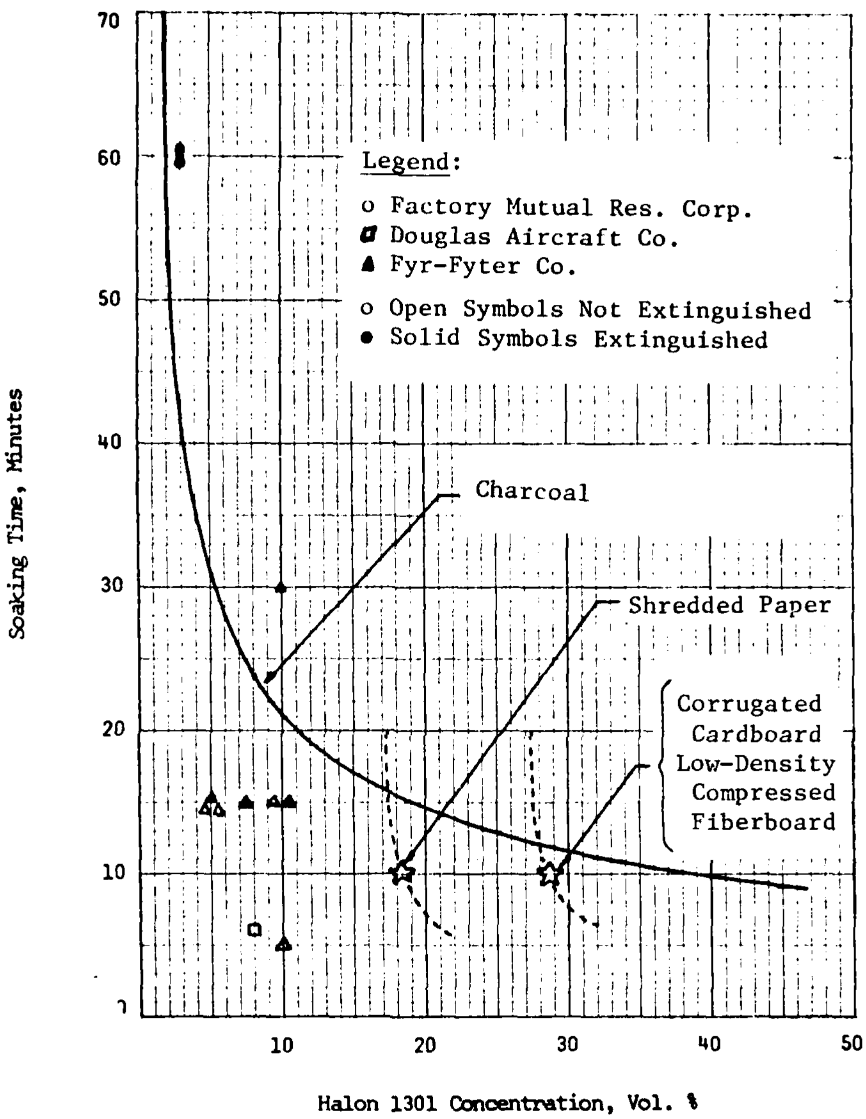

FIGURE 17. Soaking Time Versus Halon 1301 Concentration for Deep Seated Fires (Ref. 40).

TABLE 16. Halogenated Hydrocarbon Toxicity.

Agent Halon	Natural Vapor			Vapor Pyrolyzed at 800°C in Iron Tube		
	Mg/Liter	ppm	Anesthesia Time, min.	Mg/Liter	ppm	Anesthesia Time, min.
1011	340	65,000	1	20	4,000	10
1202	470	54,000	1	16	1,850	3
1211	2200	324,000	4	52	7,650	--
1301	5075	800,000	1	86	14,000	10
2402	1340	126,000	1-1/2	17	1,600	5

TABLE 17. Halogenated Hydrocarbon Toxicity Limits in 100 ft^3 Enclosure.

Halon	Natural Vapor lb	Vapor Pyrolyzed at 800°C lb
1011	2.12	0.125
1202	2.93	0.996
1211	13.70	0.324
1301	31.60	0.536
2402	8.35	0.106

In a total flooding fire extinguishment, toxicity is a major consideration for occupied space. Halon 1301 is considered to offer the lesser problem in this respect. Halon 1301 can be applied up to about 7 percent by volume without seriously endangering occupants during their escape. This should extinguish all surface burning and minimize growth of any preexisting deep seated fires. Thus, a two-step system appears appropriate which automatically raises Halon 1301 concentration to 7 percent, but which must be manually activated (or automatically, after suitable delay) to cause a second discharge which further increases concentration.

3.4.2.6 Nitrogen

Nitrogen acts to suppress combustion by displacing oxygen, as does CO_2. Its principal disadvantage is that is must be stored as a compressed (rather than liquified) gas and, thus, large high pressure storage tanks are required. For this reason,

nitrogen has had limited application in fire suppression; its use generally has been limited to small specialty applications. Nitrogen gas is added to Halon systems to hasten discharge.

3.4.2.7 Summary

Carbon dioxide and the halogenated hydrocarbons will rapidly extinguish most fires in confined spaces. These agents are particularly suited for applications in which a residue from an extinguishing agent might do as much or more harm than the fire. Of this group of agents, only Halon 1301 ($CBrF_3$) should be considered for flooding of occupied enclosed spaces.

Water spray is both safe and effective on enclosed space fires involving ordinary combustibles. It must be applied directly onto the burning material unless the space is very hot; then indirect application can be effective.

Additives that increase the viscosity of water can reduce its rate of runoff when applied to hot or burning surfaces. Of greater interest to this application are wetting agents, which decrease the surface tension of water and improve its effectiveness on deep seated fires.

High expansion foam was originally developed for suppressing fires in enclosed spaces such as coal mines, and has also been shown effective in compartments on ships. Its use is not recommended here due to the time required to completely fill the anechoic chamber, particularly crucial in this case since the chamber ceiling is also covered with the absorbent polymeric pyramids.

3.4.3 Fire Suppression Systems

Fire protection equipment includes agent transfer and application systems for the purpose of preventing or suppressing hazardous fire situations. This equipment can be divided into three major classifications: fixed, portable, and mobile systems. Fixed systems are designed to provide protection at a specific site, usually against a well-defined hazard. Portable equipment

is that which is manually moved from its storage location to a hazard. This equipment provides protection over an area in which potential hazardous situations may occur. Mobile systems include vehicle and even airborne systems to provide protection against hazardous situations that may occur anywhere in or near the plant. These will generally be a part of the supportive effort of nearby fire departments and will not be treated here.

3.4.3.1 Fixed Systems

These fire protection systems include prepositioned nozzles and hose reels connected to an extinguishing agent supply. Foam, water, CO_2, and dry chemical are all used in fixed systems. Those systems using water or foam-water are generally connected to water mains and a large if not unlimited supply of water is required to be available. Dry chemical and CO_2 are stored at the site in self-contained units.

Prepositioned nozzles provide spot coverage in areas where the hazard is well defined physically. The agent/application techniques most commonly used are outlined:

1. Automatic Spray Sprinklers - Conventional sprinkler heads with a spray pattern, automatically opened individually by heat.
2. Water Deluge Sprinkler - An array of normally open spray nozzles with a common water supply control valve; opening of the valve, manually or automatically, supplies water to all the sprinklers simultaneously.
3. CO_2 - Open nozzles supplied from storage through a manual or automatically actuated valve; CO_2 supply may be either high pressure cylinders or low pressure refrigerated storage.
4. Halon - Similar to Item 3.
5. Dry Chemical - Open nozzles supplied from container; agent is expelled by N_2 pressure supplied by high pressure cylinders.
6. Flash - Popup Water Spray Nozzle - Used to cover wider areas such as loading or service ramps; combination of water deluge system and lawn sprinkler systems; manually operated; limited actual use.
7. High Expansion Foam - Fairly complex generating equipment dumps the foam directly into the space to be protected through short duct runs.

The advantages or prepositioned nozzle systems include rapid response, efficient agent distribution, independence of operator skill, and nonexposure of an operator to hazards. Even if the nozzle application does not reach the entire fire, it will generally contain the fire and limit fire damage, allowing time for other fire control operations. For the anechoic chamber, with its high fuel concentration on all surfaces, a custom designed system is most appropriate if water is the agent chosen. Special application nozzles will be required to direct the water to all surfaces including the ceiling. The ceiling applications will be particularly crucial due to the three dimensionality of the absorber pyramids.

Hose reels attached to an agent source can supply prepositioned nozzles or be used as hand-held lines. These should be considered a "back up" and, for all but the smallest of anechoic chambers, should be restricted to water as the agent. These hoses should be small diameter (1 to 1-1/2 inches), and the flow velocity (supply pressure) limited so that one person can handle each line. Lengths of 100 to 200 ft are common.

Unlike the fixed nozzle, hose stream effectiveness depends strongly on the skill of the operator. In addition, the operator must have the protective clothing of the fireman. The need or desirability of such hose stations is only positively filled if well trained operators are immediately available.

3.4.3.2 Portable Systems

Hand carried and wheeled portable fire extinguishers are common around most installations. These are often referred to as first aid firefighting equipment, indicating their purpose is to extinguish minor fires or contain medium size fires until professional assistance arrives. The most common extinguishers and their application are outlined below:

- CO_2 - high pressure cylinders from 5 to 75 lb capacity - suitable for small spill fires; very effective on incipient closed space fires if reach and access are possible.

- Dry Chemical - 5 to 30 lb hand carried and 150 to 350 lb wheeled containers of $NaHCO_3$, foam compatible $KHCO_3$, KCl, and ammonium phosphates. Useful on spill fires and small enclosed fires.

Data describing the utility of portable extinguishers are not available. Their effectiveness is strongly dependent on operator skill and their use may expose an operator to definite danger. Too often, personnel in areas protected by portable extinguishers have never read the instructions. Unless the personnel are trained in their use, most hand extinguishers are useless. For example, a 30 lb $KHCO_3$ hand portable is rated by UL at 80 B. This means a skilled operator can extinguish a naphtha pan fire of 200 ft^2 and assumes an unskilled operator can extinguish 80 ft^2. Thus, portable extinguishers are of the most value in suppressing incipient fires in enclosed compartments such as a carburetor fire or small fuel leak.

There is definite doubt about the utility of the number of portable fire extinguishers common to many industrial installations. Investigation is appropriate into what sizes and types are most useful. A qualitative evaluation indicates that a few strategically located hand portable CO_2 extinguishers and a limited number of wheeled dry chemical extinguishers might provide a balanced protection for service areas.

3.4.3.3 <u>Summary of Existing Suppression Systems</u>

The rather lengthy treatment afforded extinguishing agents would be greatly exceeded in bulk were similar treatment given all possible suppression systems. Instead, Table 18 is a summary of the data with ample references (immediately following) to further information. Systems are categorized as portable, standpipe and manual hose stations, and prepositioned systems. Subdivision is by agent used. For each system type, a general description is provided followed by a listing of applications (including other than the chamber usage). Advantages and disadvantages of each system are addressed under "comments".

TABLE 18. Fire Suppression Systems.

Type	Description	Typical Applications	Comments	Ref.
Portable Fire Extinguishers (Manual suppression)	Metallic cylinders filled with agent, pressurized or having an adjoining cartridge with potential of pressurizing the cylinder; actuated by a hand operated valve	- First line of defense against small fires	- Advantage of portability - Effectiveness is a function of the operator's skill - Limited amounts of agents contained - Possible use of wrong agent on a particular fire	13-Sec 16 11-Chap 2 1 14 15-Chap 25
Four Basic Types:				
Water Base	Includes soda acid, cartridge operated water, foam, pressurized water, and hand pump operated water extinguishers	- General Class A protection		
Carbon Dioxide	CO_2 contained as a liquid and a gas under its own pressure in an I.C.C. cylinder	- Locate near electrical equipment, food processing areas, laboratories, duplicating areas; general Class B & C protection	- Heavy, expensive cylinders - Does not leave a residue - Has a relatively short range (3' to 8') - Not adequate in windy areas and high ventilation areas	
Dry Chemical	Type basic types: (1) stored pressure, and (2) cartridge operated; they contain powder agents listed in Section B	- General Class B & C protection - Some Class A & D protection also, depending on the agent used	- Leaves a residue after use	
Liquified Gas	Includes Halon agents under nitrogen pressure	- Class B & C protection	- Lighter cylinder than CO_2 (lower pressure) - Does not leave a residue	
Standpipes and Manual Hose Station Systems	Water distribution to sprinklers and manual hose stations is made possible by an adequate standpipe system, with adequate connections for the fire department through which the system may be boosted	- All portions of each building level shall be within 30' of a nozzle, attached to a hose of not more than 100' long (min, water supply = 500 gpm @ > 65 psi at each hose station for > 30 min.)	- Effectiveness is a function of the operator's skill - Operation of high pressure hose lines can be dangerous to the inexperienced - Only effective where the water supply is adequate and reliable	8 13-Sec 15 Chap 1
NFPA Classification:				
Class I Service	A 2½" hose connection shall be provided on each floor	- Primary means of firefighting (fire dept. or trained personnel use)		
Class II Service	A 1½" hose connection shall be provided on each floor	- Occupant use hose streams		
Class III Service	A 2½" and 1½" hose line shall be provided on each floor	- For use by fire departments and building occupants		

TABLE 18. (Contd.)

Yard Hydrants and Outdoor Hose Houses	Yard hydrants are valved hose connections to a yard distribution system. Hose houses may accompany yard hydrants for a convenient supply of hose and other necessary fire-fighting equipment. Hydrants are minimally distributed by ensuring that two hose streams are available to every point of the building considered within 500' or less.	- General hose stream protection of the building structure - For use by fire departments and trained personnel only	- Effective only where water supply is adequate and reliable	13-Sec 11 Chap 2 15-Chap 15 17
Monitor Nozzle Installations	Consist of large, manually directed nozzles mounted on a fixed platform, capable of delivering adequate water for the hazard involved	- Desirable where large amounts of combustibles such as log piles, lumber piles, or railway cars are located in yards	- Effective only where supply is adequate and reliable - Effectiveness is a function of the operator's skill	13-Sec 11 Chap 22
SPRINKLER SYSTEMS				
Four Basic Types:	Specially designed fixed pipe system, distributing water to sprinkler heads following fire actuation. The system design may be pipe scheduled, but the trend today is hydraulically calculated systems. Design ranges of application are: Light hazard - .05-.10 gpm/ft^2 Ord. Hazard-Group I - .08-.16 gpm/ft^2 Ord. Hazard-Group II - .12-.19 gpm/ft^2 Ord. Hazard-Group III - .15-.21 gpm/ft^2	- General building protection	- Sprinkler systems have proven themselves over the years - Very limited use on live electrical equipment - Only effective where water supply is adequate and reliable	7,16,18 10-Chap 9 15-Chap 11 Chap 12 Chap 23 13-Sec 14
Wet Pipe System	Uses automatic sprinklers; system piping is normally filled with water	- General building protection	- The most simple and reliable system	
Deluge System	Uses open sprinklers; there is normally no water in system piping until actuation; actuation is be a supplementary detection system which electrically opens a deluge valve	- Applicable where liquid fires are likely to spread rapidly and envelope occupants present such as: airplane hangers, chemical process and storage facilities, oil-filled transformers, etc.	- Rapid detection of fire and immediate wetting where needed	
Preaction System	Uses automatic sprinklers; there is normally no water in system until actuation; actuation is by a supplementary detection system which electrically opens a control valve, filling the system piping; system is then ready to discharge upon automatic sprinkler actuation; system may be designed to cycle on and off till fire is out	- Applicable where the preaction mechanism is desirable such as: computer Rooms, department stores, etc. where building contents are particularly vulnerable to water damage	- Eliminates the possibility of premature discharge of water where this is desirable (lower possibility of water damage)	

TABLE 18. (Contd.)

Dry Pipe System	Uses automatic sprinkers; piping system is initially filled with compressed air; the system is actuated from the loss of air pressure due to automatic sprinker activation; loss of air pressure allows water pressure to open a special "dry pipe valve" and discharge through the system. Special dry pipe sprinklers are necessary in these installation.	- Used in areas subject to below freezing temperatures (unheated buildings)	- Makes subzero sprinkler operation possible - Relatively more expensive that other system types	
Water Spray Fixed Systems	Specialized sprinkler system equipped with special water spray nozzles for specific water discharge and distribution over the area protected; system is actuated manually or by automatic detection equipment normal rates of coverage are .2-.5 gpm/ft^2	- Automatic fire extinguishment of open tanks of certain flammable liquids - Exposure protection of storage tanks and equipment containing hazardous liquids through openings in fire walls and floors in certain situations - Controlled burning of some flammable liquids to reduce fire intensity until proper extinguishing equipment arrives, or allow the fire to burn itself out. - Limited use of electrical equipment protection	- Some maintenance problems associated with small water passages necessary for fire spray discharges	3 13-Sec 15 Chap 2 15-Chap 24 p 24 10-Chap 11
CARBON DIOXIDE SYSTEMS				
Three Basic Types:				
Total Flooding Systems	Includes a fixed pipe system connected to a source of CO_2 (high pressure storage or low pressure storage). Actuation is manually or by use of a detection system. CO_2 is injected into an enclosed space. The concentration of CO_2 is raised just enough to extinguish the flames. Design concentrations are based on the hazard, volume, and ventilation. The normal range of design concentration is 33-83%.	- Enclosed area applications, such as: rooms, vaults, ovens, enclosed machinery, enclosures, etc.	- Total flooding may cause anoxia to occupants; 9% is threshold limit	15-Chap 24 4 13-Sec 15 Chap 4 10-Chap 14
Local Applications	Includes a fixed piping system connected to a source of CO_2 which is directed right on to the specific hazard involved to actually blow the flames out. System is actuated manually or by use of a detection system. System design is based on rate of discharge/unit surface area of the hazard, and the type of hazard. Normal design rates of application range from .25-1 lb/min/ft^2	- Unenclosed hazards such as: dip tanks, drainboards, rolling mills, oil-filled transformers, etc.	- Not suitable for deep seated or smoldering fires - Drafts and wind currents required special consideration	

TABLE 18. (Contd.)

Hose Line Systems (Manual Suppression)	Discharge CO_2 through manually operated nozzles connected by hose or fixed piping to a CO_2 supply. Sufficient CO_2 should be provided to permit simultaneous discharge from all nozzles for at least 1 minute. Standpipe distribution systems are in limited use today.	- Used to supplement fixed protection systems or portable extinguishers	- Extinguishment depends greatly on the skill of the operator	
DRY CHEMICAL SYSTEMS				
Three Basic Types:	There are several types of pre-engineered systems on the market today, but the larger systems are usually custom engineered.			10-Chap 16 13-Sec 15 Chap 6 15-Chap 24
Total Flooding	A predetermined amount of agent is discharged through special nozzles into an enclosed space or enclosure around the hazard. System basically consists of a pressurized source of dry chemical, a manual and/or automatic detection actuating method, fixed piping and special nozzles.	- Applicable where hazard is totally enclosed or where all openings close automatically upon discharge. Only suitable for surface fires, such as flammable liquids	- Not suitable for deep-seated fires	9 11-Chap 6
Local Application	Differs from total flooding systems, *in that nozzles are arranged* to discharge directly into the fire	- Practical in situations where the hazard can be isolated from other hazards - Common is restaurant kitchen hoods	- Ineffective unless extinguishment can be immediate and there are no reignition sources	
Hand Hose Line Systems	Consists of a pressurized supply of dry chemical, with one or more hand hose lines to deliver the agent to the fire; hose stations are connected to the agent supply directly or by fixed piping. Discharge is controlled by manually actuated valves on the hose.	- Used to supplement fixed suppression systems or fire extinguishers	- Extinguishment depends greatly upon operator's skill	
HALON SYSTEMS				
Three Basic Types:			- Halon 1301 most commonly used in total flooding, due to its low toxicity (when used in concentrations below 10%)	13-Sec 15 Chap 5 5 6 12 10-Chap 15
Total Flooding System	Consists of a pressurized supply of agent, a fixed piping syste, special nozzles, and a manual and/or automatic detection means of system actuation. Agents commonly used are Halon 1301 and Halon 1211. Design concentrations range from 3-20%.	- Applicable in enclosed areas such as: vaults, ovens, storage tanks, and bins - Commonly used to protect high valued risks such as computer equipment and priceless art.	- Advantage of clean agent used - Limited effectiveness on Class A or deep-seated fires, unless design concentrations are made very high - System design necessitates matching hardware to a greater degree than other alternative system - Can be used in occupied areas - Excellent for use on delicate electrical equipment	11-Chap 7

TABLE 18. (Contd.)

Local Application Systems	System components are the same as a total flooding system, except for the local discharge nozzles directed into the hazard	- Local applications such as: printing presses, dip and quench tanks, spray booths, oil-filled electric transformers, vapor vents, etc.		
Specialized Systems	These systems, commonly using Halon 1301 or Halon 1211, are in common use in a wide variety of situations, The distinguishing characteristic of these types of systems, is that each system can only be applied for the hazard it was specifically designed and tested for.	- Specialized systems include: aircraft engineer nacelle systems, racing car systems, military vehicle systems, emergency generator motor systems, etc.		
<u>HIGH EXPANSION FOAM SYSTEM</u>	High-expansion foam is usually generated in foam to solution volume ratios of 100:1 to 1000:1		- High-expansion foam systems should not be applied to: - chemicals which release their own oxygen to sustain combustion - energized enclosed electrical equipment - water reactive metals	13-Sec 15 Chap 3 2 15-Chap 24 10-Chap 13
Three Basic Types:				
Total Flooding Systems	- Consists of fixed foam generating apparatus with a piped supply of foam concentrate and water, arranged to discharge into an enclosed space or enclosure about the hazard - The minimum design rate of foam discharge is calculated to ensure a minimum foam depth of 1.1X the highest hazard, where submergence volume must be maintained for 30-60 minutes - Actuation is manual or by automatic detection equipment	- Effective where there is permanent enclosure about the hazard that is adequate to enable the required amount of foam to be built up inside, e.g. rooms, vaults, storage areas, warehouses, etc.	- Effective on both Class A and Class B combustibles - Effective on both surface and deep-seated fires - Care must be considered in design of occupied areas to provide adequate exit time before flooding	10-Chap 2 11-Chap 4 15-Chap 24 10-Chap 13
Local Application Systems	- Consists of fixed foam generating apparatus with a piped supply of foam concentrate and water, arranged to discharge foam directly onto the fire - The minimum design rate of foam discharge is calculated to ensure covering the hazard with > 2 feet foam within 2 minutes - Sufficient foam and water shall be provided for continuous operation for > 12 minutes - Actuation is manual or by automatic detection equipment	- Effective for use on flammable and combustible liquids, and ordinary Class A combustibles where the hazard is not totally enclosed - These systems are best adapted to protection of flat surfaces such as confined spills, open tanks, drainboards, curbed areas, pits, etc.	- Care must be considered in design of occupied areas	2-Chap 3 11-Chap 4 15-Chap 24 10-Chap 13

TABLE 18. (Contd.)

Portable Foam Generating Devices	- These devices consist of a high-expansion foam generator, manually operable and transportable, connected by means of hose and/or piping to a supply of water and foam concentrate - The minimum design rate of foam discharge is calculated to fit the specific hazards considered, using total flooding calculations or local application calculations, where necessary	- These devices may be used to combat fires on hazards similar to those described above, but where the need for portability is necessary	- Effectiveness is somewhat dependent on operator's skill	2-Chap 4 11-Chap 3 15-Chap 24 10-Chap 13

REFERENCES FOR TABLE 18

1. Portable Fire Extinguishers '74, NFPA 10.
2. High Expansion Foam Systems '70, NFPA 11A.
3. Water Spray Fixed Systems '73, NFPA 15.
4. Carbon Dioxide Systems '73, NFPA 12.
5. Halon 1301 Systems '73, NFPA 12A.
6. Halon 1211 Systems '73, NFPA 12B.
7. Sprinkler System Installation '74, NFPA 13.
8. Standpipe and Hose Systems '74, NFPA 14.
9. Dry Chemical Systems '73, NFPA 17.
10. "Fire Protection for the Design Professional," R. Jensen.
11. "Fire Suppression and Detection Systems," J.L. Bryan, 1974.
12. Symposium on an Appraisal of Halogenated Fire Extinguishing Agents, '72, National Academy of Sciences.
13. NFPA Fire Protection Handbook, 14th ed.
14. "Advanced Fire Extinguishers for Aircraft Habitable Compartments," S. Atallah, J. Hagopian, A. Kalelkar.
15. Handbook of Industrial Loss Prevention, 2nd ed., FM.
16. "Fire Behavior and Sprinklers," N. Thompson '64, NFPA.
17. Outside Protection, NFPA 24, 1973.
18. Fire Protection by Sprinklers, NFPA Pub. SSP-30.

It should be particularly noted that for each system, means must be provided to accommodate the introduction of the agent.

- drains for water systems
- pressure venting for gaseous systems

In the case of gaseous systems, once pressure venting has been accomplished, further agent escape or dilution must be prevented by "buttoning up" the space.

4. RECOMMENDATIONS

4.1 Absorber Materials

Principal materials evaluation and test developed have been by the Naval Research Laboratories (NRL) (Refs. 4, 5, 7 and 8). NRL has developed five fire performance tests (Appendix B); and these have been adopted as performance guides by various agencies. To the best of our knowledge, no material is presently available that totally satisfies the requirements of:

- absorber characteristics
- fire performance (NRL)
- cost.

Our recommendation, as of this date, is that candidate anechoic chamber absorber materials be tested by the NRL test methods and be required to meet at least three of the NRL test requirements, namely (Appendix B):

- Test 1 - Resistance to Electrical Stress
- Test 2 - Ease of Ignition and Flame Propagation
- Test 3 - Modified Smoldering Test (Revised 1976).

Other considerations (absorption characteristics, etc.) being equal, final material selection should be based on the degree of performance in NRL:

- Test 4 - Toxic Gas Emission in a Fire Environment
- Test 5 - Toxic Gas Emission Due to a Hot Surface.

4.2 Shielding

The introduction of any metal objects (probes, detectors, suppression devices, etc.) into the chamber produces some degradation in absorption characteristics. Thus, all metal parts should remain outside the chamber or, if this is impossible:

- be imbedded within absorber pyramids, or
- placed at the base juncture of pyramids.

Techniques for minimizing the effect of necessary intrusions into the chamber are described in detail in subsection 2.2 of this report.

4.3 Fire Detection

To minimize the costs associated with frequent false alarms, two fire detection techniques should be employed or two levels of sensitivity should be used. Thus, the first system or level of detection should alert local staff to a potential problem, and confirmation detection by the second system or level should trigger automatic suppression and provide a general alarm. We prefer the use of two independent detection techniques (systems) as opposed to one technique operated at two levels.

4.3.1 Alerting

Early warning is best provided by smoke detection. For use in anechoic chambers, we recommend either of the following.

1. Projected beam detection which requires a light source (visible, IR, or UV) to be projected across the chamber to a sensor at the opposite side. Sources and sensors (several beams) can be nestled at the base juncture of adjacent absorber cones to minimize interference with chamber performance. Most, if not all, metal components can be external to the chamber. A prescribed reduction in signal received due to smoke in the beam would trigger the initial alert and possibly activate the second detector system.
2. Air samples from an array of perimeter locations can be drawn through tubing to a centralized external detector package. At this location, air samples are sequentially monitored for indications of smoke or combustible gas development. Again, receipt of a positive signal would initiate a local alert and, perhaps, activate the second detector system. This system is far superior to techniques which monitor chamber exhaust ducts since air in the exhaust is a composite of the entire chamber, and any smoke therein has been drastically diluted.

Should unanticipated requirements predicate the use of "spot" ionization or photoelectric detectors, it is recommended that devices be built in two parts, sensor and signal conditioning electronics, so that the sensor can be extended away from the

base of the absorber pyramids as far as possible. The pyramid base juncture location is an extremely insensitive location for "spot" detection due to lack of adequate air circulation to these locations. It should be noted that ionization detectors within the anechoic chamber may require "top-hat" shields of perforated foil, further degrading their performance.

4.3.2 Alarm/Suppression Initiation

It is recommended that general alarm and activation of automatic suppression follow detection of open flame or heat. Open flame detectors have the potential advantage of more rapid response, but require the detector to be on a "line of sight" of the flame. For the proposed application, such detectors would have to be enclosed by an absorber cone which is automatically ejected upon the alert signal of the smoke detection system. The geometry of the chamber suggests that detectors be placed near the mid-point of each wall, ceiling, and floor.* Each would monitor the surface directly opposite. The choice between UV, IR, or both ranges of detection should address the expected potential false alarm signals in response to predicated chamber activities. Sensors for these systems are relatively high maintenance devices.

Heat detection is accomplished with simple, low maintenance devices. Commercial heat detectors are generally of metal, but devices of alternate construction could be readily devised. Fine wire thermocouples feeding an external millivolt monitor provide a viable alternate means of sensing. Sensor placement is critical, since heat must reach the device(s) in order to elicit response. Thus, numerous detection locations are required. The incorporation of fine wire thermocouples near the inlet of tubes feeding a centralized smoke/gas detection system may provide the most practical means of accomplishing both roles of detection.

*Chamber performance may constrain this to an off-center location outside the area of primary reflections.

If closed head sprinklers are chosen for suppression, they also serve the role of heat detectors to initiate suppression.

4.3.3 Under Floor System

Preliminary plans for the Harpoon Lab Anechoic Chamber indicate an under floor space (with lift out floor panels) is contemplated. This space should contain a separate system since it is expected that the space will not be "sterile" and, in fact, will be the site of "temporary wiring". For this space a "cross zoned" system is recommended to provide "alert" upon first detection and "alarm/suppress" should the second zone be actuated. Suggested spacing is 900 ft^2/detector with no forced air movement, or 450 ft^2/detector should the space also provide air handling services. Projected beam detection appears to be less practical here due to several areas where the hidden space extends upward in "pedestals". Remote sampling could be advantageously applied, particularly if that system is employed in the main chamber.

4.4 Fire Suppression/Extinguishment

4.4.1 Overview

Halon 1301 fire suppression systems are installed in and are proposed for a number of anechoic chambers. These systems are actuated by a fire detection system and flood the entire space with Halon 1301. The concentration of the agent within the protected space is intended to be sufficient to extinguish the type of fire anticipated. Halon is recommended by Rantec for chambers using fire retardant foam.

CO_2 is normally suitable for protecting the same fire risks as Halon 1301. Although no installations of CO_2 systems in anechoic chambers were identified, there is no apparent reason they cannot be used.

Automatic water sprinkler systems are commonly used in anechoic chambers containing both fire retardant and nonfire retardant foam. The most common configurations feature pop-out heads attached to telescoping piping which are normally concealed. In

case of fire, water pressure is used to extend the piping into the chamber. Either open head or closed head sprinklers may be used.

Factory Mutual tests have shown that a 7 percent Halon concentration would extinguish a fire retardant anechoic foam ignited in a standard corner test. (The FM corner test is intended to evaluate the fire risk of polymer foam interior finishes. The foam to be tested is installed on walls and ceiling in a corner and exposed to a very hot and intense wood crib fire.) This type of fire we classify as a surface fire.

There are no test data and inadequate fire experience on which to determine what minimum design concentration of either Halon 1301 or CO_2 is necessary to extinguish a well developed deep seated fire. Some existing systems appear to be designed to extinguish a surface fire but not necessarily a deep seated fire.

A Halon 1301 or CO_2 system which would extinguish surface fires only, is reasonable to consider only if either:

1. deep seated fires will not occur with the type of combustible material present, or
2. the fire detection system will provide early warning and will actuate the Halon or CO_2 system before a deep seated fire can develop.

No data have been discovered to support the first condition.

In addition, there is neither test data nor experience to support the assumption that the detection systems in common use will actuate the extinguishing systems before a deep seated fire can develop. That assumption may be valid for certain fire scenario/detection system combinations but may not for others. Smoke detectors, which are commonly used to provide early warning of fire, have varying responses to different fires and smoke. Some are relatively insensitive to large smoke particles. In addition, a ventilating system may delay smoke reaching a detector. Also, certain ignition scenarios may produce a deep seated fire before significant smoke reaches the chamber interior (e.g., resistance heating or hot surface ignition).

Although some of the current design assumptions of Halon 1301 and CO_2 systems may not be confirmed, there is experimental data to indicate that existing fire extinguishing systems may contain or retard a deep seated anechoic foam fire and any exposure fires. Fire tests in simulated aircraft cargo compartments have shown that 3-1/2 percent Halon 1301 will suppress flaming combustion and retard deep seated combustion sufficiently to keep the temperature below 400°F for about 2 hours. Other tests have shown that 3 to 5 percent Halon 1301 or 20 to 30 percent CO_2 can suppress flaming combustion in fires involving cellulosic materials although it would not suppress deep seated glowing and smoldering combustion even with long soaking times.

Halon 1301 and CO_2 can extinguish deep seated fire in cellulosic materials with higher concentrations and moderate soaking times. Tests have shown that deep seated fires require 20 to 30 percent Halon 1301 or 60 to 70 percent CO_2 for complete extinguishment. The associated soaking times ranged from 10 to 30 minutes. However, in very deep seated and insulated fires, such as found in the hold of a ship, concentrations of 90 percent CO_2 with several days soaking time were required for complete extinguishment. In some actual ships hold incidents, CO_2 extinguishment was not completely successful.

When comparing the tabulated design concentrations and weights of Halon 1301 and CO_2, it is important to consider the background related to the NFPA standards on each. CO_2 systems have been available for years; the first NFPA standard for CO_2 systems was started in 1928. The original concentrations and criteria can be considered "brute force" approaches with substantial safety factors. However, Halon 1301 was first used as an extinguishing agent in the late 1940's but it was not commercially used for other than aircraft until 14 to 20 years later. Because of the high agent cost "brute force" criteria were not feasible and little, if any, safety factors are believed included in the standard design concentrations.

4.4.2 Candidate Systems

Candidate fire suppression (and perhaps extinguishment) systems for anechoic chambers are:

- Halon 1301, total flooding
- Carbon Dioxide, total flooding
- Automatic sprinklers, deluge or closed head

Standpipes and hose lines manned by properly trained and equipped crews are recommended for backup suppression and overhaul for all systems. The choice of optimum primary system is not as certain due to unknowns in the absorber material fire performance. Thus, other considerations are drawn into the decisionmaking process.

4.4.2.1 Water Systems

Water damage to the absorber material suggests that water suppression be relegated to the backup role (standpipes and hose lines) in anechoic fire protection. By this means, water damage may be limited to a localized area in large chambers. However, if spaces surrounding and in intimate contact with the chamber house high value equipment, the cost of this equipment may be traded off against water damage to the chamber interior. This consideration is particularly of concern if backup protection (manpower) is not always on sites or otherwise quickly available.

Both automatic, built-in, water suppression systems and manual hose lines dictate that drainage be incorporated into the chamber design adequate for the potential water application rate.

4.4.2.2 Halon 1301 Systems

There are concerns that Halon systems may not extinguish all deep seated fires. However, newer absorber materials should reduce the propensity of such fires. Halon systems will suppress surface fires and should delay the impact of those with deep seated characteristics to permit backup extinguishment.

Halon systems offer the advantage that concentrations (7 percent) can be achieved which suppress surface fires while supporting life. Thus, a 7 percent system can be discharged before the space is evacuated. (Evacuation is still necessary due to potential toxicity problems from Halons decomposed by any remaining deep seated fire.)

The cost of accidental or malicious discharge becomes a severe penalty to large Halon installations, and other systems may deserve greater consideration.

Sufficient agent should be incorporated in the system to permit two successive discharges. The first, to provide 7 percent concentration, should be automatically actuated. The second, to maintain soak time and/or increase Halon concentration to combat deep seated fire should be manually actuated, or sufficiently delayed to permit manual intervention. Proper initial venting, and ultimately "button-up" is required.

4.4.2.3 <u>Carbon Dioxide Systems</u>

Carbon dioxide systems also may not extinguish all deep seated fires. Arguments for Halon systems in this regard also apply to carbon dioxide.

Carbon dioxide systems must not be discharged until the chamber is evacuated. This time should be selected for the particular chamber, and start of a countdown signalled with the initiation of the "alarm" (as opposed to the "alert"). Manual intervention should be possible to hasten or delay discharge should the situation so dictate.

A "two shot" system is recommended for use with CO_2. The first, automatic discharge, should raise CO_2 concentration to at least 34 percent by volume in the chamber. The second "shot" should be manually controlled (or capable or being overridden) to maintain "soak time" and/or to increase CO_2 concentration to about 75 percent by volume.

Carbon dioxide systems appear particularly advantageous to large chambers (cost) where adequate backup is readily available. The ability of chamber electronics to withstand thermal shock (sudden cooling) is a constraint. Proper initial venting and, ultimately, "button up" is required.

4.4.2.4 Agent Comparisons for the Harpoon Lab Anechoic Chamber

A comparison of the features and approximate costs of the candidate primary fire suppression systems for the proposed Harpoon Lab Anechoic Chamber is presented in Table 19. These are based on preliminary drawings indicating the chamber to be about 28 x 44 x 28 ft high. Detailed design and cost level estimates can be provided if desired.

As indicated near the bottom of Table 19, the under floor space should be protected with a gaseous system.

4.4.2.5 Human Interaction

It is important to stress that human interaction with the "automatic" system is an important part of total system performance. Regardless of the final selection of detection and suppression systems, optimum performance lies in:

- proper system design and installation
- proper staff indoctrination
- proper system maintenance
- proper staff training and drilling.

By these means, the system will perform when needed, and staff assistance will provide moderation of false actuation and optimization of delivery when required.

TABLE 19. Comparison of Candidate Primary Fire Suppression Systems for Harpoon Lab Anechoic Chamber.

	Halon 1301	Carbon Dioxide	Water Sprinklers
Agent requirements for surface fires			
Percent design concentration	5 to 7 percent	34 percent min. by standard	0.6 gpm/sq ft
Total weight or gpm	682 lb to 976 lb	1712 lb	900 gpm
Agent requirements for deep seated fires			
Percent design concentration	5 to 20 percent*	65 to 75 percent	0.6 gpm/sq ft
Total weight or gpm	682 lb to 3241 lb	4194 lb to 5564 lb	900 gpm
Soaking period	Yes	Yes	No
Damage potential from discharge			
Electrical and electronic equipment	Corrosion possible from agent pyrolysis products in long soak; same risk exists from combustion products.	None from agent as long as discharge is arranged to avoid cold shock.	Avoidance requires thorough washdown with mild detergent solution; clean rinse water, and drying.
Foam	None	None	Manufacturers of fire retardant foams claim water will not wash out carbon; cones must be carefully dried. Weight or absorbed water may pull cones from wall or ceiling; fall can fracture tips.
Outside chamber	None	None	Significant unless adequate drainage.
Hazard to anyone inside at discharge	Minimal at 5 to 7 percent concentration, must be evacuated first at higher concentration.	High, must be evacuated before discharge.	None if power is shut down at discharge
Estimated system cost			
One shot	$30,000 at 5 percent	$48,000 at 34 percent	$15,000**
Two shot	$45,000	$68,000 at 75 percent	NA
Direct cost of discharge	$4,000 at 5 percent	$100 at 34 percent	NIL
Qualitative indirect costs incurred in discharge (beyond that associated with fire)	None	None	Remove all cones and send back to manufacturer for drying out. Replace broken cones.
Test or field experience	7 percent extinguishes surface fires in fire retardant cones ignited using FM corner test.	None with these foams.	Extinguishes fires in all types of foam (eventually).
Suitability for use in this under floor space	Yes	Yes	No

* Deep seated concentration is speculative.

** Assumes adequate water available for sprinklers and backup hose lines.

REFERENCES

1. Plonus, M. A., "Ignitability of Anechoic Chamber Foam by Electric Currents", Proceedings Letters, Proceedings of the IEEE, Vol. 63, No. 9, p 1371, September 1975.

2. Eadens, D. P. and J. W. Connolly, "Report of Fire Investigation, Anechoice Chamber in Building 400", NAVMAT Report 11320-1, Naval Air Rework Facility, Alameda, California, February 13, 1974.

3. Williams, F. W. and H. W. Carhart, "Investigation of Fire in NRL Building 56", NRL Letter Report 6180-412:FWW:HWC:bh, November 19, 1973.

4. Tatem, P. A. and F. W. Williams, "Flammability and Toxic-Gas Production from Urethane Foams Used in Anechoic Chambers", NRL Report 7793, Naval Research Laboratory, Washington, DC, September 13, 1974.

5. Tatem, P. A., P. D. Marshall and F. W. Williams, "Modified Smoldering Test of Urethane Foams Used in Anechoic Chambers", NRL Report 8093, Naval Research Laboratory, Washington, DC, March 9, 1977.

6. "ECCOSORB HT: High Temperature and High Power Microwave Absorber", Technical Bulletin 8-2-7, Rev. 5/75, Emerson & Cuming, Inc., Canton, Massachusetts.

7. Tatem, P. A., P. D. Marshall and F. W. Williams, "Correlation of Large and Small Scale Tests on Carbon-Impregnated Polyurethane Foams", Journal of Fire and Flammability, Vol. 8, pp 180-192, April 1977.

8. Tatem, P. A. and F. W. Williams, "Development of Fire Performance Tests for Carbon-Impregnated Polyurethane Foams", Ind. Eng. Chem., Prod. Res. Dev., Vol. 14, No. 3, pp 204-210, September 1975.

9. Stone, J. P., "Transport of Hydrogen Chloride by Water Aerosol in Simulated Fires", J. Fire and Flammability/Combustion Toxicology, Vol. 2, pp 127-138, May 1975.

10. Stone, J. P. and F. W. Williams, "Transport of Hydrogen Cyanide by Water Aerosol in a Simulated Fire Atmosphere", J. Combustion Toxicology, Vol. 4, pp 231-235, May 1977.

11. Fielding, G. H., F. J. Woods and J. E. Johnson, "Halon 1301: Mechanism of Failure to Extinguish Deep Seated Fires", J. Fire and Flammability, Vol. 6, pp 37-43, January 1975.

12. Rodkey, F. L. and R. F. Robertson, "The Solubility of Hydrogen Cyanide in Water," J. Combustion Toxicology, Vol. 6, pp 44-47, February 1979.

13. Vance, E. F., "Design Guidelines for Treatment of Penetrations Entering Communication Facilities," SRI, Menlo Park, California, August 1975.

14. "Grounding, Bonding, and Shielding Practices and Procedures for Electronic Equipments and Facilities," DOT/FAA Report #FAA-RD-75-215, December 1975 (Available through NTIS).

15. "EMP Engineering Practices Handbook," NATO File No. 1460.2, October 1977 (Project Officer: Defense Nuclear Agency).

16. "EMP Protection for Emergency Operating Centers," U.S. Department of Defense, Office of Civil Defense, Report TR-61 A, May 1971.

17. "Special Issue on Shielding," IEEE Trans. Elect. Compatibility, Vol. EMC-10, No. 1, March 1968.

18. Nichols, J. F., "Simplified RF Electromagnetic Shielding," LectroMagnetics, Inc., Los Angeles, California, Report TR-105, presented at the Lawrence Radiation Laboratory, Univ. California, March 1968.

19. Bukowski, R. W., T. E. Waterman and W. J. Christian, "Detector Sensitivity and Siting Requirements for Dwellings," for National Bureau of Standards, published by National Fire Protection Association as NFPA No. SPP-43, August 1975.

20. Harpe, S. W., T. E. Waterman and W. J. Christian, "Detector Sensitivity and Siting Requirements for Dwellings, Phase 2," for National Bureau of Standards, published by National Fire Protection Association as NFPA No. SPP-43A, July 1976.

21. Waterman, T. E., K. Mniszewski and D. Spadoni, "Cost Benefit Analysis of Fire Detection Systems," for National Science Foundation and National Fire Prevention and Control Administration, September 1978.

22. "Local Protective Signalling Systems," National Fire Codes, National Fire Protection Association, NFPA 72A-1975, Boston, Massachusetts.

23. "Auxiliary Protective Signalling Systems," National Fire Codes, National Fire Protection Association, NFPA 72B-1975, Boston, Massachusetts.

24. "Remote Station Signalling Systems," National Fire Codes, National Fire Protection Association, NFPA 72C-1975, Boston Massachusetts.

25. "Proprietary Signalling Systems", National Fire Codes, National Fire Protection Association, NFPA 72D-1975, Boston, Massachusetts.

26. "Central Station Signalling Systems", National Fire Codes, National Fire Protection Association, NFPA 71-1974, Boston, Massachusetts.

27. Grabowski, G. J., "Fire Detection and Actuation Devices for Halon Extinguishing Systems", (a part of Ref. 33).

28. "Single and Multiple Station Smoke Detectors", UL 217, Underwriters Laboratories, Inc., October 1978.

29. "Smoke Detectors for Fire Protective Signalling Systems", UL 268, Underwriters Laboratories, Inc., September 1979 (effective date: March 30, 1981).

30. Fry, J. F. and C. Eveleigh, "The Behavior of Automatic Fire Detection Systems", Building Research Establishment Current Paper, Fire Research Station, ENGLAND, CP 32/75, April 1975.

31. "Automatic Fire Detectors", National Fire Codes, National Fire Protection Association, NFPA 72E-1978, Boston, Massachusetts.

32. Lee, T.G.K., "An Investment to Evaluate Smoke Detectors", Center for Fire Research, National Bureau of Standards, NBSIR 78-1430, February 1978.

33. "An Appraisal of Halogenated Fire Extinguishing Agents", Proceedings of a Symposium held April 11-12, 1972 at National Academy of Sciences, Washington, DC, conducted by Committee on Fire Research NAS/NRC.

34. Wakeley, H. G., "An Assessment of Planning and Training for Fire Safety in Health Care Facilities", Final Report, Grant No. T-9023, IITRI Project J6398, IIT Research Institute, for National Bureau of Standards, August 1978.

35. Haessler, W. M., "The Extinguishment of Fire", Revised Edition, NFPA No. FSP-40, National Fire Protection Association, Boston, Massachusetts, 1974.

36. "The Halogenated Extinguishing Agents", NFPA Report Q 48-8, National Fire Protection Association, Boston, Massachusetts, 1954.

37. McKinnon, G. P. (editor), "Fire Protection Handbook", 14th Edition, National Fire Protection Association, Boston, Massachusetts, 1976.

38. "Halogenated Fire Extinguishing Agent Systems, Halon 1301", National Fire Codes, National Fire Protection Association, NFPA 12A-1977, Boston, Massachusetts.

39. "Fire Suppressive Systems Tested", Aviation Week and Space Technology, April 14, 1969.

40. Ford, C. L., "Extinguishment of Surface and Deep Seated Fires with Halon 1301", (a part of Ref. 33).

41. Malcom, J. E., "Research and Development Program of the Bromotrifluoromethane Fire Extinguisher", U.S. Army Research and Development Laboratories, TR-1550-TR, October 1958.

42. Musick, J. K. and F. W. Williams, "The Use of Halons as Fire Suppressants - A Literature Review", NRL Report 8161, Naval Research Laboratory, October 5, 1977 (AD No. A050098).

APPENDIX A

PERFORMANCE SPECIFICATIONS FOR ANECHOIC CHAMBER MATERIALS

APPENDIX A*

PERFORMANCE SPECIFICATIONS FOR ANECHOIC-CHAMBER MATERIALS

TEST 1 - RESISTANCE TO ELECTRICAL STRESS

Specimens: Three 2- x 6- x 6-in. samples.

Equipment: A 240-V ac power supply capable of 8-A output; test leads of 10 AWG copper wire with a 90° bend 0.75 from the ends.

Procedure: The insulation is removed from the test leads to expose 0.5 in. of bare wire. The leads are inserted to a depth of 0.5 in. in the foam, 1 in. apart. The surface area of the specimen in which the test leads are inserted shall not be covered with a surface fire retardant. Power shall be applied to the specimen for 60 s. The specimen fails the test if it does not self-extinguish (no visible flame, smoke, or smoldering) within 60 s after the power has been turned off. The specimen is then left undisturbed for 30 min. At the end of this period, the specimen is inspected and damage to the specimen is rated visually: 1) no damage; 2) minor damage; 3) extensive damage; 4) total destruction (only char remaining). The specimen is then opened to expose its interior and is inspected for any evidence of remaining combustion (hot embers, smoke, or flame); any visible combustion is reported. Any specimen that is totally destroyed has failed the test. Failure of any specimen rates the material as unsatisfactory.

TEST 2 - EASE OF IGNITION AND FLAME PROPAGATION

Specimens: Five cubes, 2 in. or larger on each side.

Equipment: A laboratory ringstand with necessary clamps suitable for supporting and positioning the specimen; a laboratory Bunsen burner adjusted to a height of 3 in. and producing a flame temperature of 2000°C; a timing device permitting measurements of intervals of 1 s or less.

*Pages 13-16 of "Flammability and Toxic-Gas Production from Urethane Foams Used in Anechoic Chambers," Tatem and Williams, NRL Report 7793.

Procedure: The test shall be conducted in a location free of drafts. The specimen is exposed so that the flame is directed at the bottom center of each specimen for 30 s. The bottom of the specimen shall not be covered with surface fire-retardant paint. If the burning part of the specimen melts or shrinks away from the flame, the burner should be moved so that the specimen is continuously in the flame. If the specimen self-extinguishes (no visible flame, smoke, or smoldering) within 60 s after the flame is withdrawn, it has passed the ignition test. For a material to be classified as self-extinguishing by this test, every specimen must self-extinguish within 60 s after flame withdrawal.

TEST 3 - SMOLDERING

Specimens: Three 4-in. cubes.

Equipment: A radiative cartridge heater, capable of being inserted snugly into a 3-in.-deep hole in the side of the specimen and of reaching a maximum temperature of 600°C.

Procedure: The tests are conducted in a laboratory hood. The temperature of the heater is raised to 600°C before inserting it into the specimen. The heater is left in the specimen for 10 min, then removed. The specimen is left undisturbed for 30 min. At the end of this time, the specimen is inspected and damage to the specimen is rated visually: 1) no damage; 2) minor damage; 3) extensive damage; 4) total destruction (only char remaining). The specimen is then opened to expose its interior and is inspected for any evidence of remaining combustion (hot embers, smoke, or flame); any visible combustion is reported. Any specimen that is totally destroyed has failed the test. Failure of any specimen rates the material as unsatisfactory.

TEST 4 - TOXIC-GAS EMISSION IN A FIRE ENVIRONMENT

Specimens: Three 1-g quantities of 0.25-in. cubes.

Equipment: A combustion boat capable of containing 1g of the specimen; a 2000°C hydrogen/air torch adjusted to a height of 0.5 to 1 in. (either the boat or the flame must be movable to allow exposure of the entire sample to the flame during the test; total involvement of the sample is required); a closed chamber capable of containing the boat with the specimen and the torch, equipped to remotely ignite the torch and sample the concentrations of

CO, HCl, HCN, and O_2 and large enough that the O_2 does not fall below 20 percent during the test; detector tubes or other instrumentation for measuring the concentrations of CO, HCN, and HCl gases at the end of the test.

Procedure: The combustion boat containing the specimen is placed in the closed system. The torch is remotely ignited and directed from an angle above the specimen for 15 min; the flame should be within 0.25 in. of the specimen. During this time, the entire specimen must be exposed to the torch. At the end of the 15-min exposure, the concentrations of HCN, HCl, and CO are measured. Their productions are reported in terms of milligrams of combustion product per gram of specimen. If toxic-gas production exceeds the following limits, the specimen has failed the test.

Combustion Product	Amount of Product per gram Specimen (mg)
HCN	0.3
HCl	0.4
CO	20.0

Failure of any of the specimens rates the material as unsatisfactory.

TEST 5 - TOXIC-GAS EMISSION DUE TO A HOT SURFACE

Specimens: Three 1-g quantities of 0.25-in. cubes.

Equipment: The combustion boat, closed chamber (large enough that the O_2 concentration does not fall below 20 percent during the test) and sampling devices used in Test 4; a radiative cartridge heater capable of generating a temperature up to 350°C. The heater shall be placed on top of the cubes in the boat so that it heats all of the sample during the test.

Procedure: The combustion boat containing the 0.25-in. cubes is placed in the closed system with the heater lying on top of the cubes, so that it heats all of the specimen. The heater is then remotely activated and allowed to heat to 350°C. The specimen is heated at this temperature for 15 min. At the end of the 15-min exposure, the concentration of CO, HCN, and HCl gases are measured and reported in terms of milligrams of combustion product per gram of specimen. If toxic-gas production exceeds the following limits, the specimen has failed the test.

Combustion Product	Product per gram of Specimen (mg)
HCN	0.6
HCl	0.9
CO	5.0

Failure of any of the specimens rates the material as unsatisfactory.

A summary of the performance tests described above is given in Table A-1.

TABLE A-1. Summary of Performance Specification Tests.

Test	Equipment for Test	Property Tested	Experimental Conditions	Requirements Under Test Conditions
1. Resistance to electrical stress.	Power supply (capable of 240 V ac) Test leads.	Ability to withstand electrical overload or short.	Exposure to 240 V ac for 60 s.	Self-extinguish within 60 s after removal of ignition source and intact specimen at end of 30 min.
2. Ease of ignition and flame propagation.	Bunsen burner Support for specimen Timing device.	Ignitability and ability to self-extinguish flame (flaming ignition source).	Exposure to flame for 60 s.	Self-extinguish within 60 s after removal of ignition source.
3. Smoldering	Radiative cartridge heater (capable of 600°C).	Ability to self-extinguish smoldering (flameless ignition source).	Exposure to 600°C radiative heat source for 10 min.	Intact specimen following test.
4. Toxic-gas emission in a fire environment.	Combustion boat H_2/air flame Closed chamber.	Toxic gas production under continuous exposure to flaming ignition source (T = 2000°C).	Exposure to flame for 15 min.	HCN concentration <0.3 mg/g HCl concentration <0.9 mg/g CO concentration <20 mg/g
5. Toxic-gas emission due to a hot surface.	Combustion boat Radiative cartridge heater Closed chamber.	Toxic gas production under continuous exposure to flameless ignition source (T = 350°C).	Exposure to radiative heat source for 15 min.	HCN concentration <0.6 mg/g HCl concentration <0.9 mg/g CO concentration <5 mg/g

APPENDIX B

PERFORMANCE SPECIFICATIONS FOR ANECHOIC-CHAMBER MATERIALS

APPENDIX B*

PERFORMANCE SPECIFICATIONS FOR ANECHOIC-CHAMBER MATERIALS

TEST 1 - RESISTANCE TO ELECTRICAL STRESS

Specimens: Three 5.2 cm x 15.1 cm x 15.1 cm (2-in. x 6-in. x 6-in.) samples. The surface area of the specimen in which the test leads are inserted shall not be covered with a surface fire retardant.

Equipment: A 240-V ac power supply capable of 8-A output; test leads of 10 AWG copper wire with 90° bends 1.9 cm (0.75 in.) from the ends.

Procedure: The insulation is removed from the test leads to expose 1.3 cm (0.5 in.) of bare wire. The leads are inserted to a depth of 1.3 cm (0.5 in.) in the foam, 2.54 cm (1 in.) apart. They are horizontally supported so that they do not rest on the specimen. Power shall be applied to the specimen for 60 s. The specimen fails the test if it does not self-extinguish (no visible flame, smoke, or smoldering) within 60 s after the power has been turned off. If it does self-extinguish, the specimen is left undisturbed for 30 min and then reinspected; any specimen that is more than 90% (by weight) destroyed has failed the test. The specimen is then opened to expose its interior and is inspected for any evidence of remaining combustion (hot embers, smoke, or flame); any visible combustion rates the material as unsatisfactory.

TEST 2 - EASE OF IGNITION AND FLAME PROPAGATION

Specimens: Five cubes, 5.2 cm (2 in.) or larger on each side. The bottom of each specimen shall not be covered with surface fire-retardant paint.

Equipment: A laboratory ringstand with necessary clamps, suitable for supporting and positioning the specimen; a laboratory Bunsen burner adjusted to a height of 7.6 cm (3 in.) and producing a flame temperature of 1900°C; a time device permitting measurements of intervals of 1 s or less.

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*Pages 11-13, and 3 of "Modified Smoldering Test of Urethane Foams Used in Anechoic Chambers," Tatem, Marshall and Williams, NRL Report 8093.

Procedure: The test is conducted in a location free of drafts. The specimen is exposed so that the flame is directed at the bottom center of each specimen for 30 s. If the burning part of the specimen melts or shrinks away from the flame, the burner is moved to keep the specimen continuously in the flame. If the specimen self-extinguishes (no visible flame, smoke, or smoldering) within 60 s after the flame is withdrawn, it has passed the ignition test. For a material to be classified as self-extinguishing by this test, every specimen must self-extinguish within 60 s after flame withdrawal.

TEST 3 - MODIFIED SMOLDERING TEST (REVISED 1976)

Specimens: Three cubes, 20.1 cm (8 in.) on each side.

Equipment: A high-density electric cartridge heater 1.3 cm (0.5 in.) in diameter and 15.1 cm (6 in.) long, capable of being inserted snugly into a 7.6-cm (3 in.) deep hole in the specimen and of reaching a maximum temperature of 600°C; two thermocouples, capable of measuring temperatures to 1000°C.

Procedure: The tests are conducted in a laboratory hood. One thermocouple is physically attached by temperature-resistant tape to the cartridge heater and inserted vertically into a hole in the specimen 7.6-cm (3 in.) deep. The second thermocouple is inserted into the specimen top 2.54 cm (1 in.) from the cartridge heater. Both the thermocouple and cartridge heater/thermocouple pair are supported so that they remain upright and imbedded in the specimen throughout the test. The heater is inserted in the specimen and the temperature is raised to 600°C. The heater is left in the specimen at 600°C for 5 min before being removed. The temperature of the thermocouple 2.54 cm (1 in.) from the heater is monitored throughout the test period. The test is considered over only when all visible smoldering has ceased (no smoke, flame, or hot embers). The specimen has failed if at any time during the test period the temperature of the thermocouple 2.54 cm (1 in.) from the heater exceeds 450°C $\pm$ 10°.

TEST 4 - TOXIC GAS EMISSION IN A FIRE ENVIRONMENT

Specimens: Three 1-g quantities of 0.63-cm (0.25 in.) cubes.

Equipment: A combustion boat capable of containing 1 g of the specimen; a 2400°C hydrogen-air torch adjusted to a height of 1.3-2.54 cm (0.5-1 in.) (either the boat or the flame must be movable to allow exposure of the entire sample to the flame during the test - total involvement of the sample is required); a closed chamber capable of containing the boat with the specimen and the torch, equipped to ignite the torch remotely and sample the concentrations of CO, HCl, HCN, and O_2 and large enough that the O_2 concentration does not fall below 20% during the test; detector tubes or other instrumentation for measuring the concentrations of CO, HCN, and HCl gases at the end of the test.

Procedure: The combustion boat containing the specimen is placed in the closed system. The torch is remotely ignited and directed at an angle, from above the specimen for 15 min at a distance no greater than 0.63 cm (0.25 in.) from the specimen. During this time, the entire specimen must be exposed to the torch. At the end of the 15-min exposure, the concentrations of HCN, HCl, and CO are measured. Their productions are reported in terms of milligrams of combustion product per gram of specimen. If toxic gas production exceeds the following limits, the specimen has failed the test.

Combustion Product	Milligrams of Product per gram of Specimen
HCN	0.3
HCl	0.4
CO	20.0

Failure of any of the specimens rates the material as unsatisfactory.

TEST 5 - TOXIC GAS EMISSION DUE TO A HOT SURFACE

Specimens: Three 1-g quantities of 0.63-cm (0.25-in.) cubes.

Equipment: The combustion boat, closed chamber, and sampling devices used in Test 4; a radiative cartridge heater capable of generating a temperature up to 350°C.

Procedure: The combustion boat containing the cubes is placed in the closed system with the heater lying on top of the cubes so that it heats all of the sample during the test. The heater is then remotely activated and allowed to heat to 350°C. The specimen is heated at this temperature for 15 min. During this time, the sample must be totally involved. At the end of the 15-min exposure, the concentration of CO, HCN, and HCl gases are measured and reported in terms of milligrams of combustion product per gram of specimen. If toxic gas production exceeds the following limits, the specimen has failed the test.

Combustion Product	Milligrams of Product per gram of Specimen
HCN	0.6
HCl	0.9
CO	5.0

Failure of any specimen rates the material as unsatisfactory.

TABLE B-1. Summary of Performance Specification Tests.

Test	Equipment for Test	Property Tested	Experimental Conditions	Requirements Under Test Conditions
1. Resistance to electrical stress.	Power supply (capable of 240 V ac, 8 A), test leads located 2.5 cm apart.	Ability to withstand electrical overload or short.	Exposure to 240 V ac for 60 s.	Self-extinguish within 60 s after removal of ignition source. Specimen damage <90%.
2. Ease of ignition and flame propagation.	Bunsen burner Support for specimen Timing device.	Ignitability and ability to self-extinguish flame (flaming ignition source).	Exposure to flame for 60 s.	Self-extinguish within 60 s after removal of ignition source.
3. Smoldering	Radiative cartridge heater (capable of 600°C).	Ability to self-extinguish smoldering (flameless ignition source).	Exposure to 600°C radiative heat source for 5 min.	Specimen damage <90%.
4. Toxic gas emission in a fire environment.	Combustion boat H_2/air flame Closed chamber.	Toxic gas production under continuous exposure to flaming ignition source (T = 2400°C).	Exposure to flame for 15 min.	HCN concentration <0.3 mg/g HCl concentration <0.4 mg/g CO concentration <20 mg/g
5. Toxic gas emission due to a hot surface.	Combustion boat radiative cartridge heater Closed chamber.	Toxic gas production under continuous exposure to flameless ignition source (T = 350°C).	Exposure to radiative heat source for 15 min.	HCN concentration <0.6 mg/g HCl concentration <0.9 mg/g CO concentration <5 mg/g

APPENDIX C

FIRE RETARDANT TEST

APPENDIX C

FIRE RETARDANT TEST

AAP TEST REPORT TR-100

AAP-TR-100

SEPTEMBER 5, 1975

PURPOSE

The purpose of this test report is to detail the methods and results of a test performed to evaluate the burning characteristics of AAP loaded foam microwave absorbers. Tests were performed on samples which had been processed using an improved fire retardant formulation developed at AAP.

TEST SPECIFICATION

Tests used were intended to determine the resistance to continual flame, burning, smouldering and smoking of microwave absorber products. Each sample was subjected to the application of a propane torch flame directly to the absorber's surface for a specific time period.

RESULTS

Sections of AAP-8 pyramidal absorbers were used for this test. The methods and formulation used to process these samples was representative of that used on all of the loaded foam absorbers. In this way the results are applicable to all types and sizes.

Samples were subjected to the flame of a propane torch in two directions for a period of forty-five (45) seconds. In each case, the flame extinguished within five (5) seconds and all smouldering and resulting smoking ceased within forty-five (45) seconds. These results were noted for both painted and unpainted samples.

SUMMARY

It has been determined that Advanced Absorber Products loaded foam microwave absorbers, when processed using a new improved fire retardant formulation, can be classified as fire retardant and will carry the FR designation (Example AAP-8FR).

The results further show that the fire retardance far exceeds the "Self Extinguishing" requirement normally applied to this product.

It should also be emphasized that the temperature of the flame source used for this test is about double that specified for the "Self Extinguishing" test and still the material extinguishes immediately upon removal of the flame source.

The improved product also maintains desired features in that the absorbers are flexible and the carbon loading will not rub off during cutting and handling.

TEST DATA

TEST A - PERPENDICULAR BURNING

Flame Source - Propane Torch
Flame Size - Length 3 inches
Distance to Sample - Blue tip at surface (see sketch)
Time Flame Applied - 45 seconds
Sample Size - 8 inch pyramid (see sketch)
Sample Designation - AAP-8-FR

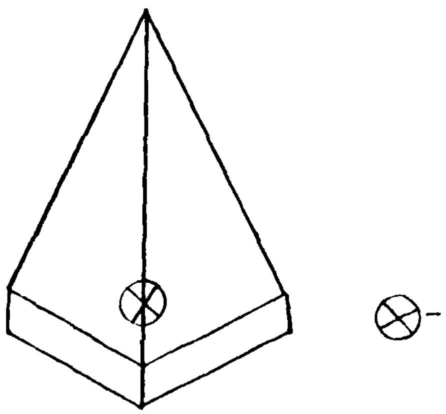
The propane torch flame was applied for 45 seconds perpendicular to the edge of the pyramid shape at a point five (5) inches below the tip of the pyramid. This test was repeated on five (5) samples with and without surface finish.

RESULTS

During the application of the flame, pressure caused a hole to be generated in the edge. The sample exhibited a bright glowing while the flame was applied.

All flame ceased within five (5) seconds after the removal of the flame on each sample.

All glowing and smoking ceased within forty-five (45) seconds after removal of flame. (Low - 15 seconds, High - 45 seconds).



X Designates direction of flame applied to sample.

TEST DATA

TEST B - PARALLEL BURNING

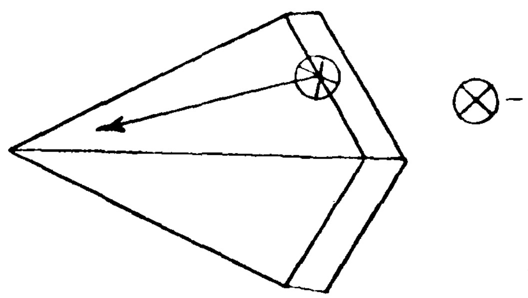
Flame Source - Propane Torch
Flame Size - Length 3 inches
Distance to Sample - At surface (see sketch)
Time Flame Applied - 45 seconds
Sample Size - 8 inch pyramid (see sketch)
Sample Designation - AAP-8-FR

The propane torch flame was applied for 45 seconds parallel to the flat surface of the pyramid. The torch tip was placed against the sample surface during test allowing the flame to cover the entire length of the pyramids flat surface. This test was repeated on five (5) samples with and without surface finish.

RESULTS

The entire pyramid side exhibited a bright glowing while the flame was applied. All flame ceased within five (5) seconds upon removal of propane flame.

All glowing and smoking ceased within twenty (20) seconds of removal of propane flame.



X Designates direction of flame applied to sample.

APPENDIX D

COMBUSTION-LIMITING ABSORBERS

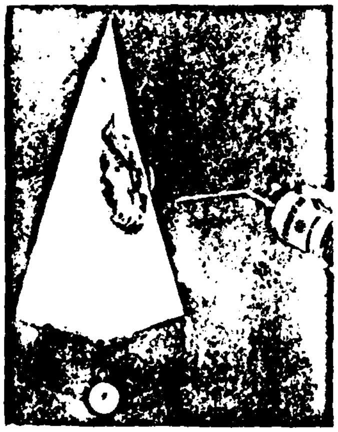
Appendix D

Combustion-Limiting Absorbers - EHP-CL Series

TEST 1 — ELECTRICAL STRESS

The electrical stress test simulates the hazard of fires caused by malfunctioning drop cords and improper electrical grounds. In the conduct of the test, two electrodes made from solid 10 AWG copper wire are separated by one inch and inserted one-inch deep into the absorber. Voltage from a 240-volt, 8-ampere (minimum) power supply is applied to the electrodes for 60 seconds. The absorber is required to completely self-extinguish within 60 seconds after power removal.

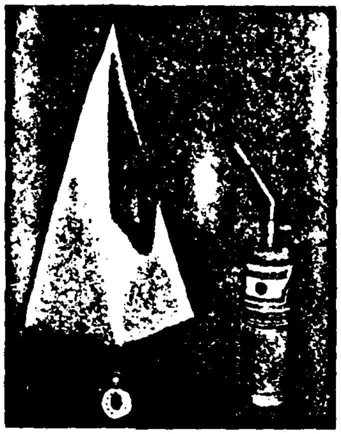
Typical "CL" material is self-extinguished in 20 seconds or less with only minimal damage.



TEST 2 — EASE OF IGNITION & FLAME PROPAGATION

This test exposes unpainted absorber to the open flame of a Bunsen burner for 30 seconds. The absorber is required to self-extinguish within 60 seconds after removal of the flame.

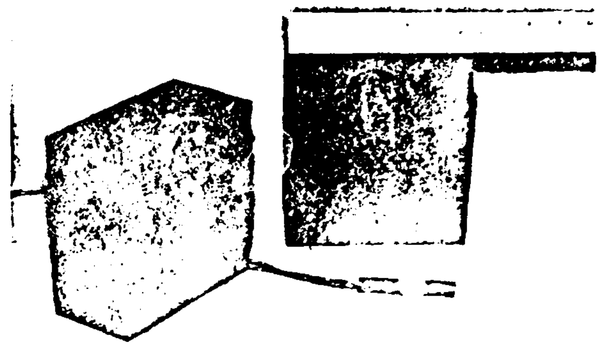
With the Type "CL" material, flames self-extinguish immediately following removal of the burner. All smoke ceases within 30 seconds and the thickness of the damaged layer is typically less than one-half inch. The accompanying photographs show the Type "CL" material being subjected to the more severe flame of a propane torch.



TEST 3 — SMOLDERING TEST

The most difficult type of fire to protect against is a slow, glowing charcoal-like combustion. In this test, a cartridge is inserted into a cored-out hole in a 6-inch cube of absorber, is raised to a temperature of 600°C (red hot), and is held at that temperature for 5 minutes. If the specimen has been burned more than 50 percent by weight or if the glowing continues beyond a period of 30 minutes, the sample has failed the test. Conventional material is totally destroyed by this test.

On the other hand, combustion in Type "CL" absorber ceases in from 3 to 5 minutes after cartridge removal with less than 20 percent material destruction. Diameter of the burned cavity is typically less than 2½ inches.



Ability of the EHP-CL absorbers to pass the foregoing combustion tests lies in the completely homogeneous impregnation of the material with a proprietary fire-retarding agent. With this treatment, the gaseous low-molecular-weight hydrocarbon fuel typically generated by burning polyurethane foam is transformed into a char- and flame-retardant pyrolytic carbon.

The absorbent material is flexible and strong and can be cut and shaped without loss of fire protection. Electrical performance is the optimum expected of modern absorbers — at both normal and off-normal angles of incidence.

APPENDIX E
FIRE DETECTION DEVICES, A SUMMARY DESCRIPTION

FIRE DETECTION DEVICES

Device	Description	Applications	Unique Characteristics	Reference
I. MANUAL FIRE DETECTION				
Manual fire alarm stations (manual device)	a. Familiar fire alarm pull boxes utilizing coded or noncoded alarm switching. For coded operation, they contain mechanically or electrically driven motors which turn a code wheel to successively open and close an electric circuit to identify location (also, digital transmission can be used). Location is generally in the normal path of exit travel, and not more than 200 ft apart.	- Manual fire detection - Watchmen supervisory service - Fire control equipment actuation	- False alarms caused by people are a problem in some areas - Only effective where people are present - Generally high operational reliability - Low maintenance - *In common use for a long time* - Overall effectiveness is dependent on the people in the area	1 2 3 4
	b. Fire alarm call boxes, which provide direct voice communication with caller to gain specific information	- Manual fire detection	- relatively new to fire communications use	
II. HEAT ENERGY DETECTORS				
A. Fixed Temperature Types				
	Designed to alarm when the temperature of the operating element reaches a specified point. Specified actuation temperatures range from 135-375°F	- General spot detection - General area detection (small area) - Suitable for releasing device service	- Subject to fewer inadvertent alarms than other detector types due to its simplicity of design - Limited to environmental temperature conditions - Very high reliability - All of these types are in common use today - Low sensitivity to Class A and C fires, high sensitivity to Class B fires	5 6 2 7 8 3
1. Eutectic metal type	Eutectic metals, alloys of bismuth lead, tin, and cadmium, are the operating elements which melt rapidly at a predetermined temperature. Electric alarm actuations are commonly designed in two ways: a. eutectic metal is placed in series with a normally closed circuit; *fusing of the metal* opens circuit and triggers alarm b. eutectic metal is used as solder to secure a spring under tension; fusing releases spring and opens circuit.	- Most common in sprinkler head element - Very common in restaurant automatic kitchen systems as fusible links - General spot detection - General area detection	- Device requires replacement after actuation - *Somewhat slow in operation* compared to other detectors (especially in well-ventilated and air-conditioned buildings) - Maintainability and stability is generally very high - In common use	8 2

FIRE DETECTION DEVICES

Device	Description	Applications	Unique Characteristics	Reference
2. Glass bulb type	Frangible glass bulbs similar to those used in some types of sprinkler heads can be used as actuating mechanisms. The bulb contains a liquid and a small air bubble. The bulb is used as a strut to maintain circuit contacts. As heat is absorbed, pressure is built up in bulb due to the bubble expansion; the rapid increase in pressure actuates the alarm upon the bulb's shattering.	- Common in high temperature applications - Some general spot detection - General area detection	-Requires replacement after activation	8 2
3. Continuous line types	Alternative to spot fixed temperature detection using various designs: a. A pair of wires in a normally open circuit. Conductors are insulated from each other by a thermoplastic of known fusing temperature, twisted and installed under tension. When design temperature is reached insulation melts, actuating the alarm.	- Used where continuous line heat detection is desirable	- Reliability, stability, and maintainability not yet established - Not self-restoring - "Twisto-wire" - "Protectowire"	2 8
	b. Similar device using semiconductor material and a stainless steel capillary tube. The capillary tube contains a coaxial center conductor. A small current normally flows through the semiconductor, except under fire conditions where the semiconductor resistance decreases, allowing a larger current to flow and thus actuating alarm.	- Used successfully in aircraft engine cells - Used successfully in cable trap	- Self-restoring	2 8
	c. Special capacitor cable, a ceramic core surrounded by a metal wire and covered with a metal sheath. The line capacitance at any point varies directly with the local temperature. Sophisticated electronics continuously polls several points along the line and displays results on an oscilloscope initiating an alarm when temperature is too high in any area.		- Self-restoring - New on market - Location of high temperature areas are accurate within 1 or 2 ft	8 9 10 11

FIRE DETECTION DEVICES

Device	Description	Applications	Unique Characteristics	Reference
3. Continuous line types (concl)	d. Thermoplastic fire-sensing hose, pressurized with 30 to 50 psi air pressure. Heat due to fire softens the hose which will ultimately rupture when T is approximately equal to 170°F. The decrease in pressure initiates an alarm at the control box via a low pressure switch	- Designed for coal mine use	- Very durable in situations where adverse conditions prevail which are destructive to electronic circuits - Hose requires replacement after actuation	12
4. Bimetal type	The bimetal mechanism is a sandwich of two metals having different coefficients of thermal expansion. When heated, differential expansion causes stresses in the assembly which are resolved by bending or flexing toward the metal with the lower expansion rate. There are generally two common designs:	- General spot detection - General area detection	- Self-restoring	8 2
	a. Bimetal Strip: placed directly in line of circuit. Heat may cause expansion in the direction of the contact points which are then opened.		- Lack of positive rapid action - The gradual bending as heated may result in inadvertent alarms from jarring or vibration before design temperature is reached	8
	b. Snap Disc: a bimetallic disc found in a concave shape in its unstressed condition. As disc is heated stresses developed cause convex reversal of disc, which is used to actuate alarm (cone reversal is instantaneous at design temperature)		- Not as susceptible to inadvertent alarms as bimetal strip - In common use	8
	c. Rate Compensated: a metal cylinder containing two metal struts which are the alarm contacts. With a rapid increase in temperature the shell expands, rapidly closing the struts. Under slowly increasing temperature both the shell and struts expand until the contacts close. The cylinder and struts are the two metals, but they are not bonded together.		- In common use - Rate compensated heat detection - "rate anticipation" type	
5. Synthetic filament transducers	Synthetic thread type transducers may be of use in fire detection. Device would consist of thread(s) under tension. Heat due to fire causes the threads to stretch and ultimately fail. Loss of tension can initiate an alarm.		- Research conducted in Russia on this principle (~1970) - Some U.S. patents on this principle - None are known to be on the market	13

FIRE DETECTION DEVICES

Device	Description	Applications	Unique Characteristics	Reference
6. Metal oxide thermistors	Certain metal oxides whose electrical resistance decreases orders of magnitude within a few degrees of a reasonable alarm point can be used as a fixed temperature fire detector.	- Spot type applications	- Low cost	14
7. Laser types	(See Smoke & Fire Gas Detectors)			
B. Rate of Temperature Rise Types				
	One effect a fire has on its surrounding environment is to generate a rapid increase in temperature of the air above a fire. The rate of rise detector will function when the rate of temperature rise exceeds approx. 15°F (8.33°C)/min. Normal changes in ambient temperature are compensated for within the detector.	- General spot detection - General area detection - Suitable for releasing device service	- Reacts to rate of temperature rise for faster operation than fixed temperature device - Inadvertent alarms may be caused due to heating systems, machines, etc. - High stability - Average reliability - Low maintenance - In common use - Medium sensitivity to Class A fires; high sensitivity to Class B fires; low sensitivity to Class C fires - Less sensitive if ambient temperature is high	8 5 6
1. Pneumatic	The expansion of gas when heated in a closed system is used to generate the mechanical force and actuate alarm contacts. Line systems consist of a metallic tubing in a loop configuration attached to the ceiling. Spot applications consist of heat-collecting air chambers.	- General spot and line detection - General area detection	- Self-restoring - In common use - Spot type units become more sensitive with age if dust clogs vent hole	8
2. Thermoelectric type	Various thermoelectric properties of metal have been successfully applied in devices for heat detection. The properties used are the generation of voltage between bimetallic junctions (thermocouples) at different temperatures, and variations in rates of resistivity change with temperature.	- General spot detection - General area detection - Some line type applications	- Series-linked thermocouples (thermopiles) greatly increase sensitivity of detection	15

FIRE DETECTION DEVICES

Device	Description	Applications	Unique Characteristics	Reference
III. SMOKE SENSING DEVICES				
1. Ion chamber type	Reacts to the aerosol components of combustion. Responds best to particle sizes between 0.01 and 1.0 micrometer. Normal sensitivity range is 0.5 to 3.5%/ft obscuration. The basic detection mechanism of an ionization detector consists of an alpha or beta radiation source in a chamber containing positive and negative electrodes. The radiation in the chamber ionizes the O_2 and N_2 molecules in the air between the electrodes causing a small current flow when voltage is applied. When aerosols and smoke enter the chamber ion mobility is decreased, and the resulting decrease in current actuates the alarm.	- General spot detection - General area detection - Suitable for some releasing device applications in limited cases	- Most models have adjustable sensitivity within a narrow range - Some designs are subject to changes in sensitivity with varying velocities of air entering the chamber - Sensitivity also affected by humidity altitude (low pressure) - Average maintainability and stability - Some designs are not applicable for applications where high ambient radioactive levels are present, resulting in reduced sensitivity - Self-restoring - In common use - High sensitivity to Class A and B fires and medium sensitivity to Class C fires - More sensitive to flaming fires than smouldering fires	8 2 6
2. Photoelectric type	Reacts only to aerosol components of combustion. Responds best to particle sizes greater than 0.5 micrometer. The presence of aerosols generated during the combustion process affects the propagation of light as it passes through the air. Two effects of the aerosol/air mixture are utilized to detect the presence of fire: a. Attenuation of the light intensity integrated over the entire beam path length b. Scattering of light in the forward direction and at various angles to the beam path Smoke detectors which utilize item a., consist of a light source, collimating lens system, and a photosensitive cell.	- General spot detection - Projected beam detection over large open areas - Intermittent sampling in multizone systems with one central analyzing device	- Continuous exposure of light accelerates the aging of photocells, which implies increased maintenance and possible failure - Average sensitivity, maintainability, and stability - Foreign matter in air may cause inadvertent alarm - Self-restoring - In common use - High sensitivity to Class A fires; low sensitivity to some Class B fires; medium sensitivity to Class C fires (better than ion type)	8 2 5 6
	Smoke detectors utilizing item b. operate on the forward scattering of light which occurs when smoke particles enter a normally dark chamber. They basically consist of a light source, photocell, and a special chamber to utilize the scattering principle. Normal range of sensitivity is 0.5 to 2.5% light obscuration/ft		- More sensitive to smouldering fires than flaming fires - New LED types offer more reliability than older types	

FIRE DETECTION DEVICES

Device	Description	Applications	Unique Characteristics	Reference
3. Resistance bridge type	Employs an electron grid-bridge circuit. Increases of smoke particles and moisture present in products of combustion, bring about impedance changes which upset the balance of the grid-bridge circuit causing an electronic triggering device to initiate an alarm. Atmospheric changes due to normal environmental conditions are accepted by the grid-bridge circuit and the bridge is kept in balance.	- General spot detection - General area detection	- Some difficulty with inadvertent alarms due to moisture and airborne contaminants - Average sensitivity, maintainability, and stability - Self-restoring - Less sensitive to plastics fires than cellulosic fires - Continually losing popularity	8 2
4. Particle ionization type	Determines submicrometer particle concentration by measuring the variation in electrical charge due to the pressure of ionized particles. Positive and negative ions are separated and the negative ions are used to measure a potential which is related to the concentration of particles present.	- Volume sampling (single and mutizone applications)	- Alarms in incipient stage of fire	8
5. Condensation nuclei type	Uses a technique in which micrometer or submicrometer particles can be made to act as condensation nuclei on one particle-one droplet basis; the concentration of particles is measured by photoelectric methods (normally set to alarm at 2.2×10^{10} particles/ft^3).	- Intermittent sampling in multizone systems with one central analyzing device - High valued areas, e.g., museums, art galleries, etc.	- Gaining popularity - High maintenance required - Alarms in incipient stage of fire - Extremely sensitive - Wide range of sensitivity	15 8
6. Quartz crystal incipient type	Air is pumped through a separator which selectively directs only submicron sized aerosols (~0.7 micron) to a jet nozzle type impactor, where 50% of the mass products greater than 0.3 micron in size are deposited on the face of the sensing crystal. The addition of mass through impaction of the sensing crystals causes a decrease in the resonant frequency of that crystal. A difference between the beat frequency of the sensing crystal and an identical reiterative crystal, caused by a fire condition will actuate an alarm. Normally set to alarm at 1800 g/m^3.	- Volume sampling (single zone) - Multizone intermittent sampling systems should be feasible - Developed for use in space shuttle; has been shelved due to Device 7	- False alarm free operation claimed - Insensitive to changes in gravity - Alarms in incipient stage of fire - Has alarm reset to reconfirm incipient fire condition - Insensitive to changes in air currents and dust (can operate in air currents up to 1000 ft/min) - Initiates fail-safe signal when maintenance is required - Relatively new - Requires 5 watts power consumption - Has been shelved due to Device 7	16

FIRE DETECTION DEVICES

Device	Description	Applications	Unique Characteristics	Reference
7. Modified ion chamber type	Predecessor of Device 6. Uses same type of impactor and air pump mechanism, but with ionization chambers substituted in place of the quartz crystals. Only particles less than 2 microns in size are directed through the sensing chamber.	- To be used in the space shuttle and in advanced naval craft	- Has same characteristics as Device 6	17
8. Laser types	Detects heat by reaction to changes in the index of refraction of the air along the beam of the path. This refractive index can cause variations in the velocity of the laser beam. This phenomenon is utilized by monitoring the changes in the beam path due to heat. Detects smoke by responding to the presence of visible products of combustion of a fire in the same manner as an ordinary light beam. This phenomenon is utilized by the use of photocells in the same manner as with an ordinary light beam.	- Projected beam detection across large areas	- Ambient light can have an adverse effect on smoke detection - Detection time varies with air velocity and ambient light - Reliability, maintainability, and stability are not established - Relatively new - Not known to be commercially available yet - Excellent for large, open area detection	8
IV. **FIRE GAS SENSING DEVICES**				
1. Catalytic semiconductor gas detector	Uses a bulk N-type catalytic semiconductor thermistor, which responds with a large decrease in resistance when exposed to reducing or combustible gases, due to catalytic oxidation. In simple application, the operating element is placed in series with an alarm device and the power source in the quiescent condition acts as a high resistance to block the flow of current to the alarm circuit. During a fire the element resistance drops and current flows to the alarm circuit.	- General area detection - General spot detection	- Relatively new - Value as a detector is not fully established - Self-restoring - Possible contamination of sensor - Inadvertent alarms possible due to response to gases which are not fire signatures - Reliability, maintainability, and stability have not been established but are questionable - e.g., "Taguchi" - Research needed in developing gas selective catalysts - Offshoot from gas leak detection - Poor response to plastics fires	8
2. Infrared type CO_2 detector	IR energy in the range of 4.22 to 4.31 micrometers is used to detect CO_2, the only gas to have an absorption in this range. Increased CO_2 concentration is measured by an exponential decrease in voltage due to photodetector resistance. Can detect a wide range of CO_2 concentrations	- Volume detection - Used successfully in African gold mines	- Extremely sensitive - Very expensive - e.g., "Spanair System" developed for gold mines recently - Requires more power than conventional detectors - Continuous monitoring - Has advantages over conventional mine air sampling systems due to the elimination of the time lag due to air travel through sampling hoses - Similar devices are being developed to detect methane and carbon monoxide	18

FIRE DETECTION DEVICES

Device	Description	Applications	Unique Characteristics	Reference
3. Field effect transistor hydrogen sensor	Smoke contains a small amount of hydrogen, the amount depending on the degree of combustion. More hydrogen is evolved in the early and dying out stages of fire development than during the developed fire condition. Because of this, the hydrogen output can be used to detect the early stages of a fire. Pd-gate n-channel silicon field effect transistors can be used for this purpose. Hydrogen gas is adsorbed to the metal surface and metal-oxide interface which causes a change in the threshold voltage of the MOS transistor and this change is easily measured. Concentrations as small as 1 ppm can be detected with this setup.	- Should be useful for general fire detection	- Value as a fire detector is not established - Spinoff from hydrogen leak detection - New concept - No mention in literature of possible false alarm problems - No mention in literature of sensor contamination problems - Self-resetting - 150°C temperature necessary for sensing element operation	19 20 21
4. Argon type detector	Operates on the principle of ionization of foreign molecules by collision with high energy Ar atoms leading to high concentrations of A* (see Ref. 4 for additional explanation of operation) Gas sensor beta or alpha radiation is used as a background current source.	- Should be useful for general fire detection	- New concept (probably not on market) - CO and CO_2 cannot be detected by this method - Best suited for very small concentrations of gases - Ref. 4 indicated that hybridization of this type and ionization type would be a very good combination reducing fire alarms	22
5. Flame ionization type	An H_2-O_2 flame, which is used as one of the electrodes, is used to induce electron emission in various types of organic and inorganic molecules having low work functions. Electrodes under imposed voltages are used to collect the resulting ions.	- Should be useful for general fire detection	- No fire detectors developed using this principle are known - High sensitivity, reasonable stability, moderate flow insensitivity, and linearity are reported for these devices - Continuous flow of H_2 is necessary for detector operation - Might be of value in a hybrid setup	22
6. Thermal conductivity sensors	A set of matched metal filaments or thermistors is used to follow changes in thermal conductivity. A reference gas is passed over a reference junction while the gas in question passes through the detection element. Resistance of the detection element changes in reference to the reference junction.	- Should be useful for general fire detection	- Ref. 4 explains how this device could be incorporated as a fire detector	22

FIRE DETECTION DEVICES

Device	Description	Application	Unique Characteristics	Reference
7. Fuel cell devices	Analogous to an electrochemical cell where conventional fuels react at the anode while O_2 or air reacts at the cathode.[2] Carbon monoxide fuel cells may be feasible in this type of fire detection.	- Should be useful for general fire detection	- Ref. 4 explains how this device could be incorporated as a fire detector	22
8. Oxygen depletion type	Oxygen depletion occurring in a fire situation may be useful for detection purposes. Probably best in a hybrid setup. Detection mechanisms may be primary galvanic cell: a type of battery in which electricity is generated in proportion to O_2 partial pressure (many variations with different anodes and cathodes).	- Should be useful for some fire detection applications	- e.g., solid electrolyte fuel-cell device similar to Survivair's device used in underwater diving	23 8
V. **FLAME DETECTORS**				
	Several methods are used to detect fires by sensing the radiant energy from smouldering or flaming combustion. Spectra used are in the IR (0.7 to 1.40 micrometer) and the UV (0.001 to 0.4 micrometer) bands	- General area detection - Best applied in areas where flame will initiate before smoke	- Fiber optics may be used in conjunction with these - Self-restoring - Interference from solar radiation is a major problem, causing inadvertent alarms - Advantage of large area surveillance by rapidly responding to the designed level of actuation anywhere in its range of vision.	8 5
1. Infrared type	Basically consists of filter and lens system to screen out unwanted wavelengths and focus incoming energy on photocells. Normally designed to receive either the total IR component of flame or flame flicker in the range of 1.5 to 10 Hertz or 4 to 15 Hertz.	- General area detection	- Generally high sensitivity and speed of response - Generally low stability - Low sensitivity to Class A and C fires; high sensitivity to Class B fires - Medium reliability and maintainability	8
2. Ultraviolet type	Same operating principle as IR type except operating in the UV range (0.7 to 0.30 micrometer) in which they are insensitive to both sunlight and artificial light	- General area detection	- Problems with responding to electric arcs and lighting, causing inadvertent alarms - High sensitivity and speed of response - Low sensitivity to Class A fires; high sensitivity to Class B and C fires - Medium reliability, maintainability, and stability	8
3. Combination IR-UV	Combination of the above types into one unit	- General area detection - Applied successfully in hyperbaric chambers, and aircraft minicomputers	- High sensitivity and speed of response	8

FIRE DETECTION DEVICES

Device	Description	Applications	Unique Characteristics	Reference
VI. MISCELLANEOUS DETECTORS				
1. Ultrasonic type	Sets up a stable standing wave in the area to be supervised. Movement of air caused by hot gases from a fire disturbs the wave pattern. The disturbance is monitored by an ultrasonic receiver which is used to trigger an alarm. A spinoff of intrusion detection technology.	- Volume surveillance	- High sensitivity - Supervised area must be unoccupied, for the sensor detects any movement	22 24
2. Rate of temperature rise, fixed temperature combination	Combination of two different detection mechanisms described previously, incorporated into one unit. The two most common types are: a. Vented hemispherical diaphragm for the ROR mechanism, and spring retained eutectic metal as the fixed temperature mechanism	- General spot detection - General area detection	- Advantage of quick response to rapidly developing fires by use of the ROR mechanism, while the fixed temperature elements respond to the *slowly developing* fires - Generally high maintainability, stability and reliability - In common use - Medium sensitivity to Class A fires; high sensitivity to Class B fires; low sensitivity to Class C fires.	8
3. Resistance bridge-ionization combination	Combination of the two previously described devices into one unit; each mechanism having its own bridge circuit which together must trigger a main electronic gate.	- General spot detection - General area detection	- Reduces inadvertent alarms due to the required activation of both mechanisms - Stability, maintainability, and reliability are average - In common use	9
4. Electrostatic detection	An insulated wire grid placed over and under the entire surveillance area can be used to measure "charged particles" extracted from flames. Charged particles accumulate and are detected in the form of an electric current.	- Fire surveillance of entire gridded area	- Speculative idea from Ref. 62 - Many possible sources of inadvertent alarm such as household appliances - Device may only be useful at nighttime (low activity) - Possible security applications of this device. - None of these devices have been marketed	25
5. Ionization/ fixed temperature combination	Combination of two different detection mechanisms described previously, incorporated into one unit. Activation of alarm is by either mode of detection	- General spot detection - General area detection	- Added thermostat serves as a backup detector in case of ionization failure, or as a primary detector in case of high heat buildup without smoke	
6. Photoelectric/ fixed temperature combination	Combination of two different detection mechanisms described previously, incorporated into one unit. Actuation of alarm is by either mode of detection	- General spot detection - General area detection	- Added thermostat serves as a backup detector in case of photoelectric smoke detector failure, or as a primary detector in case of high heat buildup without smoke.	

FIRE DETECTION DEVICES

Device	Description	Applications	Unique Characteristics	Reference
7. Catalytic semiconductor/ fixed temperature combination	Combination of two different detection mechanisms described previously, incorporated into one unit. Activation of alarm is by either mode of detection.	- General area detection	- Added thermostat serves as a backup detector in case of gas detector failure, or as a primary detector in case of high heat buildup without gases.	
8. Acoustical Fire Detection	Sound waves of various frequencies are emitted by the combustion of materials. With the advent of new technology in acoustical transducers, it may now be economically feasible to utilize them as fire sensors, either using combustion generated sounds or degradation sounds of a doped material as a fire signature.	- General area detection	- Speculative IITRI idea - Fire signature is sound; thus detection is with speed of sound - Does not require a line-of-sight configuration as other quick response detectors - Possible false alarm problems - Doping agents with characteristic degradation frequencies may eliminate false alarms, if necessary	

REFERENCES USED IN APPENDIX E

1. NFPA, National Fire Code 72B, "Auxiliary Signaling Systems", 1975.

2. Bryan, J. L., "Fire Suppression and Detection Systems", Glencoe Press, 1974.

3. Jensen, R., "Fire Protection for the Design Professional", Cahners Books, 1975.

4. Handbook of Industrial Loss Prevention, 2nd Edition, Factory Mutual.

5. Symposium on an Appraisal of Halogenated Fire Extinguishing Agents, National Academy of Sciences, April 11-12, 1972.

6. NFPA, National Fire Code 72E, "Automatic Fire Detectors", 1974.

7. Fire Protection Handbook, 14 Ed., NFPA.

8. Custer, R., R. Bright, "Fire Detection - The State of the Art", NBSA Center for Fire Research, NBS Tech Note 839, June 1974.

9. System Senses Temperature Along a Line, Instruments and Control Systems, 1975.

10. "1000 Ft Wire That Detects Fire," Business Week (Ind. Ed.) 1975.

11. Sanford, J., "Thermistor Defines Temperature Profile," Design News, November 1975.

12. Stitt, T., "Air Hose Replaces Electric Circuit in New Fire Detection System," Coal Age, p 88, September 1973.

13. Veselov, A., Taradaiko, V., "Synthetic Filament Transducers for Automatic Fire Extinguishing Systems and Protective Devices, Principles of Fire Prevention and Fire Fighting," Translation of Pozharnaya Profilaktika I. Tushemi, Pezarov, Moscow, 1968.

14. Lipman, J., "Build a Simple Fire Alarm with Metal-Oxide Temperature Sensors, Electronic Design," p 88, April 1976.

15. Ludewig, F., "New Concept in Fire Protection Fire Journal," 69(4), p 87, July 1975.

16. Barr, L. G., Development of a Quartz Crystal Incipient Fire Detector, Celesco Industries, Inc., Costa Mesa, California.

17. Design Discussion, Mark 2, Production Smoke Detector, Brunswick Corp., Defense Div., Report 01-579, January 1977.

18. van der Walt, N. T., "New Ways of Detecting Underground Fires Prove Their Worth in South African Mines", E/MJ, p 80, February 1976.

19. Lundstron, I., Shivaraman, M., Stiblert, L., Svensson, C., "Hydrogen in Smoke Detected by PD-Gate Field Effect Transistor".

20. Zatek, J., "How to Measure and Monitor Combustible and Toxic Gases," Fire Command, p 21, April 1973.

21. Waterman, T., Degenkolb, J., and Stickney, C., "A Study - Early Warning Fire Detection Performance in the Hospital Patient Room," Fire Technology, p 287, November 1974.

22. Wagner, J. P., "Survey of the Principal Operating Characteristics of Fire Detector Mechanisms", Fire Research Abstracts and Review, 23(2), 2971.

23. Giles, A. F., Electronic Sensing Devices, 1966.

24. Bagno, S., Gilbert, R., and Demers, E., "Fire Detection by Ultrasonic Doppler", IEEE Convention Record, p 193, 1964.

25. Greason, W. and Inculet, I., "Electrostatic Fire Detection", IEEE Trans. IGS-7(1), p 89, January/February 1971.

26. Hurle, I. R., et al, "Sound Emission from Open Turbulent Premixed Flames", Proc. Roy. Soc. A. 303, 409-427, 1968.

27. Strahle, W. C., "A Review of Combustion Generated Noise", AIAA Aero-Acoustics Conference, Seattle, Wash., October 1973.

APPENDIX F
ORGANIZATIONS RESPONSIBLE FOR FIRE PROTECTION REQUIREMENTS

ORGANIZATIONS RESPONSIBLE FOR FIRE PROTECTION REQUIREMENTS

F.1 Authority

The promulgation and enforcement of fire protection requirements in the United States is carried out by all levels of government. Whereas tradition placed the onus of responsibility on local government, increased realization of the magnitude of fire protection problems has created a trend toward more centalized unified governmental action (Ref. 1). That the trend is incomplete is borne out by a statement by the Committee on Fire Safety Aspects of Polymeric Materials of the National Materials Advisory Board, "Only the United States, among developed nations, has a widely fragmented system of fire safety standards and codes" (Ref. 2).

The role of legislative and administrative bodies relative to fire laws vary from level to level of government, and from region to region in state and local governments. At the federal level, legislature generally provides an enabling law and administrative agencies implement specific provisions (often based on consensus fire safety standards). In other cases, particularly at state or local levels, legislative action may clearly dictate the implementation required.

State and local laws affecting public fire safety draw on the tenth amendment to the Constitution as "reserved to the states" (Ref. 1). Local laws, in effect, gain their power by delegation from their state's Constitution and laws. The shift to increased municipal home rule has resulted in less control at the state level. However, an equivalent increase in local control is not realized because of federal preemption.

F.1.1 State Fire Laws

State fire laws are normally implemented by the Office of State Fire Marshal. In most states the fire marshal has the power to make regulations which have the effect of law. Among the typical responsibilities of state fire marshals are:

- fire prevention
- storage, use and sale of combustibles and explosives
- installation and maintenance of
  - fire alarm systems
  - fire suppression systems
- fire escapes
- fire exits
- fire investigation and arson control
- fire protection in high-rise structures

F.1.2 Local Fire Laws

Local fire laws draw heavily on nationally recognized standards, modified for local purpose. Local fire laws generally related to buildings or to hazardous materials, processes or equipment used in buildings (Ref. 1). Enforcement responsibility is usually distributed between separate agencies; fire departments and building departments.

Police departments also may play a role. In some states, local fire marshal's offices are established, operating in a manner similar to a state fire marshal's office, but, on a local level.

F.1.3 Federal Fire Laws

Federal regulatory power is inferred from Article 1, Section 8, Clause 3 of the Constitution, which gives Congress the power to regulate interstate commerce (Ref. 1). Proponents of federal regulation presume that a local fire disaster can impact transportation of that local product to other industries in other states, in turn affecting further production at these distant locales. Thus, to protect the general public, federal regulation of interstate commerce is employed. Laws passed by Congress may provide that (Ref. 1):

- all state laws on the subject are superseded,
- state laws not in conflict are valid, or
- the more stringent law (state or federal) will prevail.

Congress has delegated the promulgation of regulations to various departments and agencies. These generally match to general area of responsibility of the agency and are summarized in a later section. It should be noted that until recent years there was no federal focus in terms of an agency with specific responsibility to coordinate federal fire safety activities. Creation of the National Fire Prevention and Control Administration in the Department of Commerce filled the void. Since its creation, the agency name has changed to U.S. Fire Administration and it is now a part of the recently formed Federal Emergency Management Agency.

F.2 Building and Fire Prevention Codes

As mentioned above, laws for fire safety fall in two general classes: those which relate to building construction criteria (building codes), and those which relate to performance criteria for hazardous processes, materials, and machinery used in buildings (fire prevention codes). Building codes usually cover the following items (Ref. 1):

- powers and duties of building officials
- building classification by occupancy
- establishment of fire zones
- height and area limits
- construction and use restrictions of buildings
- special occupancy provisions
- light and ventilation requirements
- exit requirements
- structural and material requirements
- construction requirements
- fire resistance requirements
- chimney and heating applicance requirements
- elevator requirements
- plumbing requirements
- electrical requirements
- gas piping requirements
- fire extinguishing equipment requirements

Fire prevention codes usually cover the following items (Ref. 1):

- powers and duties of fire prevention bureau
- explosives, ammunition, blasting agents, etc.
- flammable liquids
- liquified and compressed gases
- requirements for particular processes and occupancies
- combustible metals
- fireworks
- hazardous chemicals
- maintenance of fire equipment
- maintenance of exitways
- dust explosion prevention
- general precautions against fire

Building codes and fire prevention codes are adopted at municipal, county, state or federal levels as each of these organizations can be the "authority having jurisdiction". Usually, the authority will adopt, in whole or in part, a model code developed by a recognized organization of interested parties. Once adopted, the code becomes law.

Major model building and fire prevention codes are:

1. Basic Building Code (Building Officials and Code Administrators International, Inc.)
2. Uniform Building Code (International Conference of Building Officials)
3. Standard Building Code (Southern Building Code Congress International, Inc.)
4. National Building Code (American Insurance Association)
5. Life Safety Code (National Fire Protection Association)
6. Basic Fire Prevention Code (BOCA)
7. NFPA Fire Prevention Code
8. AIA Fire Prevention Code
9. Uniform Fire Code (ICBO)

Model code requirements for early warning fire detection and suppression usually reference the National Fire Protection Association's Nation Fire Codes (Ref. 3). These include:

- NFPA No. 71 - Central Station Signaling Systems
- NFPA No. 72A - Local Protective Signaling Systems
- NFPA No. 72B - Auxiliary Signaling Systems
- NFPA No. 72C - Remote Station Signaling Systems
- NFPA No. 72D - Proprietary Signaling Systems
- NFPA No. 72E - Automatic Fire Detectors
- NFPA No. 73 - Public Fire Service Communications
- NFPA No. 10 - Portable Fire Extinguishers
- NFPA No. 11 - Foam Extinguishing Systems
- NFPA No. 11A - High Expansion Foam Systems
- NFPA No. 11B - Synthetic Foam and Combined Agent Systems
- NFPA No. 12 - Carbon Dioxide Systems
- NFPA No. 12A - Halon 1301 Systems
- NFPA No. 12B - Halon 1211 Systems
- NFPA No. 13 - Sprinkler Systems, Installation
- NFPA No. 13A - Sprinkler Systems, Maintenance
- NFPA No. 14 - Standpipe and Hose Systems
- NFPA No. 15 - Water Spray Fixed Systems
- NFPA No. 16 - Foam-Water Sprinkler and Spray Systems
- NFPA No. 17 - Dry Chemical Systems
- NFPA No. 13E - Fire Department Operations in Properties Protected by Sprinkler, Standpipe Systems
- NFPA No. 27 - Private Fire Brigades
- NFPA No. 101 - Life Safety Code

Other nongovernmental agencies also provide consensus standards and codes which are, in turn, adopted by various law making bodies. Predominant among these agencies are the American National Standards Institute (ANSI) and the American Society for Testing and Materials (ASTM).

ANSI identifies, develops, and publishes national standards for public protection. It coordinates voluntary standards of various organizations to promote uniformity in content of

standards generated and/or applied by the various public and private sectors.

ASTM develops, by consensus, and publishes standards on finished products, on materials used in manufacturing and construction, and on test procedures for evaluating material or product performance exposed to environmental challenges such as fire.

F.2.1 Product Approval Standards

When enforcing a code it is often necessary for the authority having jurisdiction to recognize, or give approval to, the use of a particular device or system. It is the responsibility of this authority to approve or accept a material, process, device or installation which he knows has been investigated and approved (listed) by an agency he believes is both unbiased and reliable. Labels and recommendations of recognized testing agencies are factors to be taken into account by the authority having jurisdiction but may, if desired, be rejected and approval based on other factors considered more pertinent by that authority.

In the fire protection field, Factory Mutual Laboratories and Underwriters Laboratories are those which are nationally recognized for testing system components.

F.3 Federal Responsibilities

Federal documents can be classed as (Ref. 1):

- procurement documents,
- guideline documents, or
- regulatory documents.

The first two are directed at suppliers to the federal government; and, are usually prepared by the General Services Administration (GSA) or the Armed Services. The third class, regulatory documents, includes all mandatory standards issued and enforced by the federal government. These are predominantly developed or promulgated by the following departments and agencies.

Department of Agriculture

- U.S. Forest Service - prevention of forest fires

Department of Commerce

- Maritime Administration - development, promotion, and operation of the U.S. Merchant Marine; and, organizing and directing emergency merchant ship operations
- Office of Product Standards - policy guidance for implementing statutory responsibilities of Commerce in standardization, including industrial and consumer product standards
- National Bureau of Standards - basic standards, materials research, applied technology (includes Center for Fire Research, which plays a strong role through the development of data and tests of fire behavior and material effects)

Department of Defense

Researches, develops and promulgates in a variety of areas specific to its needs.

- Army
- Navy
- Air Force
- Defense Supply Agency

Department of Health, Education and Welfare

- Public Health Service, and
- Social Security Administration - both enforce fire protection standards related to federally assisted health care facilities
- National Institute of Occupational Safety and Health - directs research into health and safety standards and recommends standards to Occupational Safety and Health Administration (Department of Labor)

Department of Housing and Urban Development

- Minimum property standards for properties receiving mortgage assistance
- minimum property standards for health care facilities receiving mortgage insurance
- mobile home standards and safety regulations applied nationally

Department of the Interior

- Public Lands Administration Act - investigation and regulation to protect public lands from fire
- Mine Enforcement and Safety Administration - develops (with Bureau of Mines) and enforces fire protection regulations in coal, metal, and nonmetal mines

Department of Labor

- Occupational Safety and Health Administration - safety in the workplace

Department of Transportation

- United States Coast Guard - fire protection and safety on all classes of boats (dangerous cargo, noncommercial motor boats, steam vessels, etc.)
- Federal Railroad Administration - laws to promote railroad safety
- Federal Aviation Administration - fire safety in air commerce, including transportation of flammable or hazardous materials and safe construction of aircraft
- National Highway Traffic Safety Administration - safety performance of motor vehicles including transportation of flammables and explosives
- Materials Transportation Board - natural gas pipeline safety, hazardous materials transport

Department of Treasury

- Bureau of Alcohol, Tobacco and Firearms - interstate transport of explosives

Consumer Product Safety Commission

Uniform safety standards for consumer products (flammable fabrics, hazardous substances)

Environmental Protection Agency

Storage and handling of pesticides; pollution control (affects fire protection standards)

Federal Communications Commission

Use of emergency air frequencies

Federal Trade Commission

Flammable fabrics, foam plastics (the FTC, through its action against foam plastic manufacturers, associations, voluntary standards organizations, etc., had far reaching impact on all aspects of fire research, fire testing and format/scope of voluntary fire standards).

General Services Administration

Building and fire safety codes for design, construction, alteration and maintenance of government buildings (also, procurement and guideline documents, described earlier).

National Aeronautics and Space Administration

Fire safety regulations, adopted for its own peculiar hazards, have impacted standards and product development pertinent to general fire safety.

Nuclear Regulatory Commission

Fire safety in nuclear power plants

Veterans Administration

Building and fire safety standards relative to VA supported facilities (health care, etc.).

F.4 Insurance Interests

The need to insure against loss by fire, theft, damage, etc., provides an impact on the selection of fire protection devices and schemes. This may be "self-insurance" if the owner feels comfortable with the overall risk and the sizes of his potential loss, compared to the cost of premiums to an insurance agency. The U.S. government is self-insured. To the smaller owner in particular, the loss from any significant fire might prove financially catastrophic, and he looks to an insurance agency for financial protection. Firms providing such insurance, in turn, band together to spread occasional large losses over a broader base. They also form trade associations to represent their

interest in terms of public standing and legislature. The associations favor uniform nationwide codes and standards that make their risk assessments more universal. They are particularly concerned that codes not require unnecessary or "imaginary" protection since their clients, in meeting these requirements, then look to them for rate reductions that may not be justified. Principal among the associations are:

- American Insurance Association (property and casualty)
- American Mutual Insurance Alliance (mutual fire and casualty)
- Factory Mutual System (large mutual property companies)
  - Factory Mutual Engineering, Research (nationally recognized for testing and approval services)
- Industrial Risk Insurers (pool of industrial risk underwriters)
- Insurance Services Office (voluntary, nonprofit, unincorporated association of casualty and property insurers; information provided to any insurer).

REFERENCES USED IN APPENDIX F

1. McKinnon, G. P. (editor), Fire Protection Handbook, 14th Edition, National Fire Protection Association, Boston, Massachusetts, January 1976.

2. Fire Safety Aspects of Polymeric Materials, Volume 2 - Test Methods, Specifications, and Standards, Report of the Committee on Fire Safety Aspects of Polymeric Materials, National Materials Advisory Board, Publication NMAB 318-2, National Academy of Sciences, Washington, DC, 1979.

3. National Fire Codes, published annually (16 volumes) by the National Fire Protection Association, Boston, Massachusetts.

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